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UNITED STATES
DEPARTMENT OF THE INTERIOR
J. A. KRUG, SECRETARY

BUREAU OF MINES
R. R. SAYERS, DIRECTOR

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DIESEL EQUIPMENT IN UNDERGROUND MINING

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D. HARRINGTON AND J. H. EAST, JR.

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UNITED STATES DEPARTMENT OF THE INTERIOR - BUREAU OF MINES

DIESEL EQUIPMENT IN UNDERGROUND MINING[1]

By D. Harrington[2] and J. H. East, Jr.,[3]

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INTRODUCTION

Considerable interest has been shown in the prospective use of Diesel-powered haulage equipment in both coal and noncoal mines. Foreign technical magazines have devoted considerable space to discussions of the use of Diesel locomotives in European mines, and some mention of it has been made in technical papers in the United States. The Bureau of Mines has extensively tested the gases produced in the exhaust of the Diesel engine under various atmospheres and conditions of use; it has established a schedule of tests for permissibility of Diesel engines for use in underground coal mines, including gassy or dusty mines.

This publication provides information as to the successful use of Diesel-powered equipment in some underground workings in the United States and Europe, briefly discusses the characteristics of some of the toxic gases found in the exhaust of Diesel engines, and points out that Diesel-powered equipment can be used with reasonable safety in underground mines if necessary and entirely feasible precautions are taken.

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Information and report data published recently in European technical magazines have been used freely in this paper, and the publications of the Bureau of Mines and various unpublished reports of the engineers of the Bureau of Mines also have been utilized. This assistance is gratefully acknowledged, as well as that of the officials at several American mines that operate Diesel-powered haulage equipment.

HISTORY OF THE DIESEL ENGINE

The Diesel engine was invented in 1892 by Dr. Rudolph Diesel, a German scientist, but the first successful engine was completed in 1897, a single-cylinder, 25-horsepower unit. The first Diesel engine-powered locomotive for underground mines is said to have been placed in service in the Ruhr coal-mining district in Germany in 1927; in 1931 there were 57 units in the district, and by 1934 the number had increased to 115. In all of Germany, 189 Diesel locomotives were said to have been in service in underground mines in 1934.

Diesel locomotives were placed in service in French and Belgian coal mines soon after Germany demonstrated their success, both as to safety and efficiency, in underground use. The first Diesel locomotive used underground in English coal mines was placed in service in 1939; in April 1946, 40 flame-proof Diesel locomotives were in service in mines in the British Isles.

The first Diesel locomotives used underground in the United States is said to have been placed in service in 1939. The first Diesel locomotive to be used underground in a coal mine in the United States was placed in service at a western mine in 1946 under special regulations imposed by the State Mine Inspection Department. Diesel locomotives were used to good advantage by some contractors in driving portions of the Delaware River Aqueduct tunnels in New York State and were placed in service in August 1939.

PRINCIPLE OF THE DIESEL ENGINE

A Diesel engine is a high-compression internal-combustion mechanism that differs fundamentally from the gasoline engine. In the gasoline engine, fuel and air are mixed before they enter the engine cylinder; in the Diesel, fuel and air are mixed inside the cylinder. The gasoline engine compresses a mixture of gasoline and air, which is ignited by a spark; the Diesel engine compresses a charge of air into which oil is sprayed, and ignition is accomplished by the heat of compression. The air in the cylinder is compressed until its temperature is approximately 1,000°F., and a measured quantity of fuel oil is sprayed into the hot air, whereupon it burns immediately. In the Diesel engine the quantity of air in the cylinder is held constant and always exceeds the amount required to burn the fuel oil completely. The amount of fuel oil injected into the cylinders is varied to change the engine speed and power. The compression ratio is

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much higher in Diesel engines than in gasoline engines, and this is one of the important reasons for Diesel-engine efficiency, as it is a fundamental rule that increasing the compression ratio increases the efficiency of an engine.

There are two general types of Diesel engines - 4-cycle and 2-cycle.

4-Cycle Engine

Briefly, the 4-cycle engine operates as follows: The piston moves downward from the top of the cylinder, the inlet valves are open, and air is drawn into the cylinder. The piston reaches the bottom of the cylinder, and the inlet valves close. This is the first stroke. On the second stroke, the piston moves to the top of the cylinder, compressing the air to 500 or 600 pounds per square inch; the temperature of the compressed air may reach 1,000°F. Fuel in a spray is injected into the hot air at the top of the cylinder, and it burns immediately. The third stroke is known as the power stroke; the hot gases from the burning fuel oil expand, increasing the pressure inside the cylinder, forcing the piston down to the bottom of the cylinder. The fourth stroke is the one that exhausts; the exhaust valve opens, and the burned gases are swept out of the cylinder, making room for a new charge of fresh air.

2-Cycle Engine

Operation of the 2-cycle engine is similar to that of the 4-cycle engine, except that the 2-cycle engine has one power stroke for each two strokes of the piston. Compression, fuel injection, and expansion of the gases occur essentially as in the 4-cycle engine. The exhaust valve in the top of the cylinder opens when the piston is near the bottom of the cylinder and releases the burned gases. The air-inlet valve near the lower end of the cylinder opens, and the air forces the remainder of the burned gases out of the cylinder; the exhaust valve closes, and the upstroke of the piston compresses the air on another cycle. Intake of fresh air and exhaust of burned gases take place simultaneously.

GASES EVOLVED IN THE EXHAUST OF A DIESEL ENGINE

The exhaust gas of the Diesel engine consists of the products of combustion of Diesel fuel and the air in which it is burned. Diesel fuel, commonly termed fuel oil, is a hydrocarbon mixture consisting generally of about 85 percent carbon with the remainder hydrogen and possibly small quantities of sulfur. When the Diesel engine is operated within its normal range of power output, virtually all of the carbon in the fuel oil burns to carbon dioxide, and the hydrogen burns to water; any sulfur present burns to the oxides of sulfur. A small percentage of the carbon in the fuel oil does not burn to carbon dioxide, with the result that a relatively small amount of carbon monoxide is always present in the exhaust gases of a Diesel engine.

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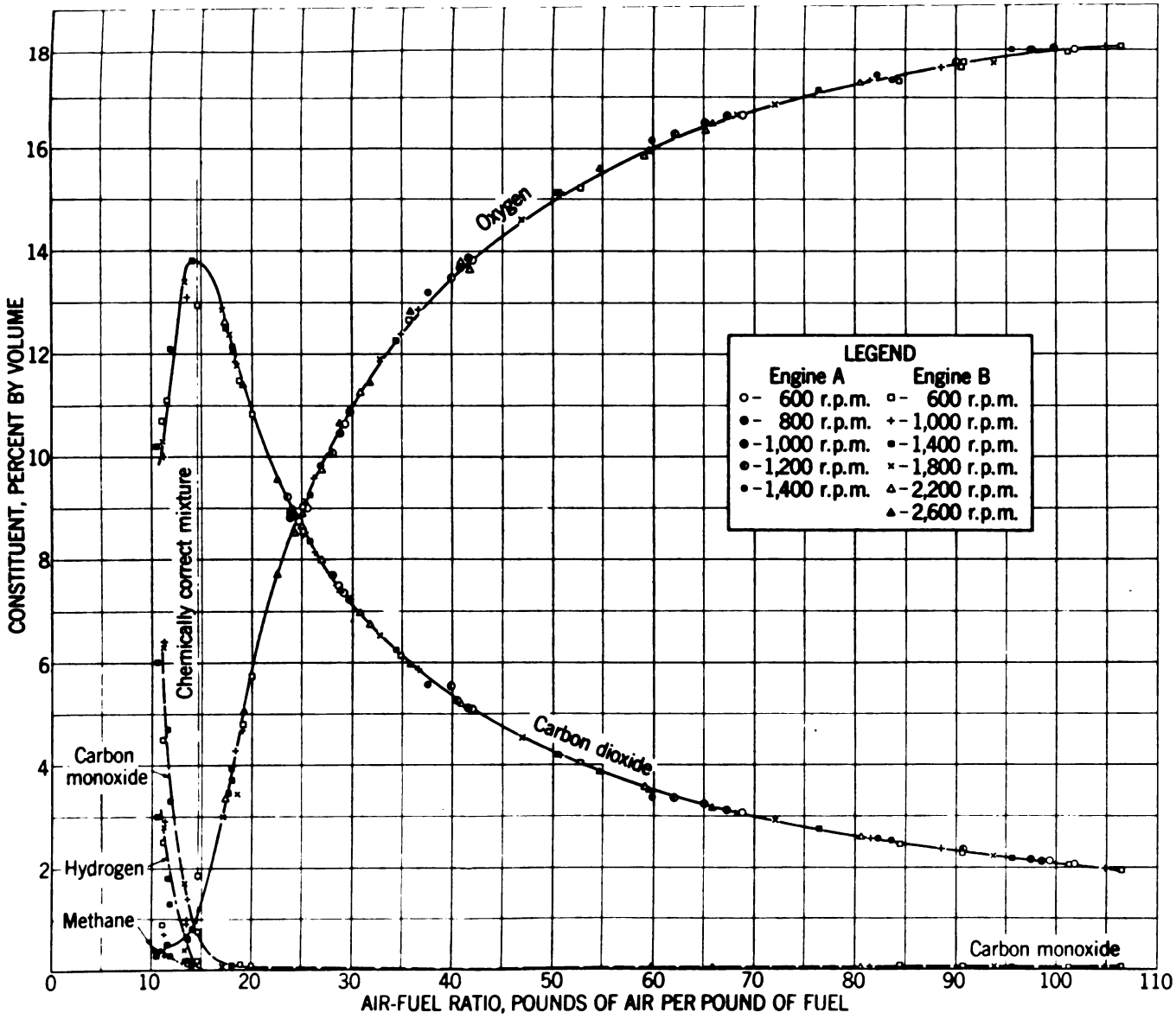

Figure 1. - Relation of composition of exhaust gas to air-fuel ratio for two different Diesel engines.

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Aldehydes are produced by the partial combustion of fuel oil in a Diesel-engine cylinder; these largely are responsible for the odor associated with the exhaust of a Diesel engine. Aldehydes in high concentrations irritate the eyes, throat, and nose.

Another byproduct of combustion in Diesel-engine operation is formed by the reaction of the oxygen and nitrogen of the air inside the cylinders during combustion. This product is termed oxides of nitrogen (NO_2). The chemical reaction takes place in the cylinders because of the high temperature in the Diesel cylinders during combustion; the fuel does not enter into this reaction.

The composition of Diesel exhaust gases depends chiefly on the air and fuel in the cylinders during combustion, or, in other words, the air:fuel ratio. The ratio is expressed in terms of weight, that is, pounds of air per pound of fuel. The air:fuel ratio is at its minimum at the minimum power output, as when the engine is idling; the ratio is maximum at full load and speed, as when the engine is working at its highest capacity. The air:fuel ratio at maximum power output, or full throttle, is the most significant, as the weight of the exhaust gases is at a maximum when the engine is working at capacity and requires full throttle or injection of fuel oil.

As the air:fuel ratio is expressed in terms of the weight of air per pound of fuel and is independent of the volume occupied by the air, the ratio varies with the altitude of the locality where the Diesel unit is operating. For example, a Diesel engine may be adjusted so that it is in perfect working condition at a 1,000-foot altitude, and the exhaust gases are well within the permissible limits; however, if the engine, utilizing the same procedure, is taken to an altitude of 8,000 feet, the air:fuel ratio will be different, as the air at that altitude is lighter in weight and a larger volume of it is required to weigh a pound. Therefore, the amount of fuel oil injected into the cylinders must be adjusted to restore the air:fuel ratio at which the engine is designed to operate, as the volume of the cylinders is constant.

The air:fuel ratio of 20 pounds of air per pound of fuel is selected generally as the most conducive to maximum efficiency of operation at full load and full speed. The exhaust gases at this ratio contain a dangerous amount of toxic and harmful gases. The chemically correct mixture for maximum oxidation of the carbon in the fuel oil to carbon dioxide is about 15:1, but at this ratio maximum quantities of carbon monoxide and hydrogen are formed, as well as a small amount of methane. (Fig. 1.)

CHARACTERISTICS OF THE DIESEL EXHAUST GASES

The principal gases composing the exhaust from a Diesel engine are carbon dioxide, carbon monoxide, oxides of nitrogen, aldehydes, oxides of sulfur, oxygen, nitrogen, and smoke.

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Carbon Dioxide

Carbon dioxide is a colorless and odorless gas; it is heavier than air and may accumulate near the floor of an inadequately ventilated tunnel or mine working. When breathed, one-half of 1 percent (0.5 percent) of carbon dioxide causes a slight increase in lung ventilation, i.e., causes deeper breathing, and 2 percent causes about 50 percent increase in lung ventilation.

Carbon dioxide is formed in the complete oxidation of the carbon in the fuel oil. The maximum carbon dioxide content of an atmosphere in which a Diesel engine can be operated safely is 1 percent, but 0.5 percent is preferable. An atmosphere containing 1 percent of carbon dioxide is not considered satisfactory for a working environment, and the Bureau of Mines recommends that the maximum allowable carbon-dioxide content of the atmosphere in mines be less than 0.5 percent.

Carbon Monoxide

Carbon monoxide is a colorless and odorless gas; it is slightly lighter weight than air, diffuses easily into the surrounding atmosphere, but may accumulate in the top of working places that are not well-ventilated. It is extremely dangerous to breathe; a carbon monoxide content of 0.20 to 0.25 percent in air that is breathed produces unconsciousness in approximately 30 minutes; a concentration of 0.04 percent causes headache and discomfort within 2 to 3 hours.

Carbon monoxide is produced in Diesel engines as a result of incomplete combustion of the carbon in the fuel oil; contrary to the belief of some people, carbon monoxide is almost always present in the exhaust fumes of a Diesel engine. A Diesel engine working within the range of the air:fuel mixtures for which it is adjusted by the manufacturer produces much less carbon monoxide than a gasoline engine, and under such conditions the amount of carbon monoxide in the exhaust gas can be diluted and removed safely by having a reasonable amount of ventilating air in the underground workings in which the Diesel-engine exhaust gas is liberated.

A Diesel engine operating at air:fuel ratios richer than the limit set by the manufacturer (usually 20 pounds of air per pound of fuel oil) may produce enough carbon monoxide to create hazards equal to those produced by a gasoline engine; it is therefore essential for safe use of a Diesel engine underground that suitable precautions be taken to prevent changing the air:fuel ratio to a mixture richer than that designated by the manufacturer. Fuel injection must be controlled by adjustment or design of equipment so that the resulting maximum air:fuel ratio will be restricted to safe operation.

Oxides of Nitrogen

The term "oxides of nitrogen" is applied to the toxic oxides of nitrogen (NO) and nitrogen peroxide (NO_2) or mixtures of them. The most serious

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consequence of inhaling these gases is the formation of nitric and nitrous acids in the respiratory organs.4/ The presence of only a small percentage of oxides of nitrogen in the atmosphere may ultimately cause death. The maximum allowable percentage of oxides of nitrogen in mine air in various States ranges from 0.001 to 0.004 (10 to 40 parts per million).5/ The maximum percentage of this gas considered permissible in the working environments by the Bureau of Mines is 0.0025 percent (25 parts per million) by volume.

An atmosphere containing one-half of 1 percent (0.5 percent) to 1.0 percent of carbon monoxide is likely to be fatal to human beings in less than 30 minutes of exposure, whereas as little as 0.07 percent of oxides of nitrogen may cause fatalities in the same length of time.5/ This is an indication of the danger from exhaust gas of Diesel engines operated in confined places when proper precautions are not taken.

Oxides of nitrogen are formed by the reaction between oxygen and nitrogen composing the air heated to a high temperature inside the cylinder of a Diesel engine. The fuel oil does not enter into this particular chemical reaction in the cylinder, and the oxides of nitrogen result solely from the reaction between nitrogen and oxygen of the air brought about by high temperatures in confined spaces.

The quantity of oxides of nitrogen produced by a Diesel engine when operating at full load and full speed is greater than when the engine is idling or running at a lower speed; this is due to the higher temperature inside the cylinder and to the increase in amount of air used in combustion of the fuel oil. The exhaust-gas cooling system in the usual up-to-date Diesel reduces the quantity of oxides of nitrogen formed, because the temperature of the exhaust gas is reduced by the water and some of the oxides of nitrogen are taken into and held in solution. The ratio of the quantity of oxides of nitrogen formed to the quantity of carbon monoxide formed in Diesel exhaust gases is not proportional, and in many instances the ratio of concentration of oxides of nitrogen to carbon monoxide was 2-1/2:1, which is within the "permissible maximum" of modern practice, but tests indicate that the ratio is always greater than 1:1. The carbon monoxide content (in percent) of the general atmosphere can, however, be used as an indicator of the percentage of oxides of nitrogen present.

European technical publications contain few data regarding the presence of oxides of nitrogen in the exhaust gases of Diesel engines; emphasis is placed almost entirely upon the amount of carbon monoxide present in the exhaust gases and in the atmosphere in which the Diesel engines are working. Tests made in the United States by the Bureau of Mines and others4/ 5/ show the presence of the oxides of nitrogen as well as carbon monoxide in sufficient quantities to warrant consideration when calculating ventilating-air requirements in mining operations where Diesel engines are used.

4/ Holz, J. C., Berger, L. B., Elliott, M. A., and Schrenk, H. H., Diesel Engines Underground. I. Composition of Exhaust Gas from Engines in Proper Mechanical Condition: Bureau of Mines Rept. of Investigations 3508, 1940, 48 pp.

5/ Ash, S. H., and Naus, L. L., Use of Diesel Locomotives in Tunnels: Bureau of Mines Inf. Circ. 7222, 1942, 26 pp.

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Aldehydes

Aldehydes are a product of the incomplete oxidation of the hydrocarbons in the fuel oil. Chemically, an aldehyde is defined as a colorless, mobile, and very volatile liquid (CH_3CHO) obtained from alcohol by moderate oxidation. However, there are many compounds in the aldehyde group; these are intermediate between the alcohols and acids and differ from the alcohols in having two fewer hydrogen atoms in the molecule. The aldehydes are named for the acids they yield on oxidation or for hydrocarbons containing the same number of carbon atoms. The aldehydes are formed only in direct oxidatio

Aldehydes have a characteristic sharp, suffocating odor and, even in exceedingly small quantities, cause irritation to the eyes and the respiratory passages, and their presence in the exhaust gas is largely responsible for the so-called "acrid exhaust" from Diesel engines; it is the only odor that can be detected in the exhaust gas, because the other gases, except the slight traces of oxides of sulfur that may be present, are odorless. The odor of aldehydes greatly resembles that of formaldehyde, which is the aldehyde of formic acid.

Aldehydes are discussed by Berger and McGuire[6/] as follows:

> The term "aldehydes," in reference to Diesel-engine exhaust gas, is used to describe certain products of partial oxidation of the fuel. Formaldehyde (H.CHO) is typical of such compounds. Aldehydes are formed by reactions that take place in the initial stages of combustion of the fuel, and if such reactions are chilled or arrested by the cooling action of engine surfaces, such as the cylinder walls, some of the aldehydes remain unburned throughout the final stages of combustion and are present in the exhaust gases discharged from the engine. Aldehydes are mainly responsible for the odor and irritating properties of Diesel-engine exhaust gas.

The odor intensity and irritating effect of undiluted Diesel-engine exhaust gas is shown in table 1.[7/]

The Bureau of Mines recommends that Diesel-engine exhaust gas, as diluted and discharged into the atmosphere, contain no more than 10 parts per million, by volume, of aldehydes (as equivalent formaldehyde) under any condition of operation.

6/ Berger, L. B., and McGuire, L. H., Observations on the Use of a Diesel Freight Locomotive Through a Railway Tunnel: Bureau of Mines Rept. of Investigations 3887, 1946, 20 pp.

7/ Elliott, M. A., Holz, J. C., Berger, L. B., and Schrenk, H. H., Diesel Engines Underground. III. Effect on Exhaust Gas Composition of Operating Engines in Mixtures of Normal Air and Natural Gas: Bureau of Mines Rept. of Investigations 3584, 1941, 50 pp.

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TABLE 1. - Relation of aldehyde concentration in exhaust gas to odor intensity and irritating effects.

Range of aldehyde concentration in exhaust gas, parts per million, by volume	Degree of odor	Degree of irritation
0 - 10	Faint	None to slight
10 - 50	Easily noticeable	Slight
50 - 100	Easily noticeable to strong	Moderate to strong
100 and over	Very strong	Intolerable

Oxides of Sulfur

The sulfur content of fuel oil is oxidized to form sulfur dioxide (SO_2) and sulfur trioxide (SO_3), but these are usually reported as sulfur dioxide.

Sulfur dioxide is a colorless, suffocating, irritating gas with a strong, pungent, sulfurous odor. It is poisonous even when present in small percentages. Although 0.04 to 0.05 percent (400 to 500 parts per million) is considered dangerous to persons on exposure of 30 to 60 minutes, the gas is so irritating to the eyes and respiratory system that it is intolerable to remain in and breathe an atmosphere containing a dangerous amount of sulfur dioxide unless the victim is unable to escape from it.

Fuel oil that is virtually free from sulfur is readily available, and most Diesel-engine manufacturers specify the maximum permissible sulfur content of the fuel.

The concentration of sulfur dioxide generally accepted as the maximum permissible for prolonged exposure is 10 parts of the gas per million parts of air by volume. If the calculated concentration of sulfur dioxide exceeds the permissible value of 10 parts per million by volume, then oxides of sulfur must be considered as a factor in establishing the quantity of ventilating air required.

Oxygen

The oxygen content of a Diesel-engine exhaust gas is always relatively high, because an excess of air over that required for complete oxidation of the fuel oil is constantly present. However, a Diesel engine consumes oxygen from the air, and this must be replaced by ventilation to maintain the oxygen content of the surrounding atmosphere at over 19 percent. The Bureau of Mines recommends that mine air contain at least 20 percent of oxygen in working sections of the mine.

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PROCEDURE FOR TESTING DIESEL MINE LOCOMOTIVES FOR PERMISSIBILITY

The Bureau of Mines is prepared to test mine locomotives powered by Diesel engines to determine their permissibility for use in coal mines and other underground operations where inflammable gases and dusts may be present. Some of the conditions a Diesel engine must meet to be designated as permissible are discussed briefly. The purpose of the tests outlined in Schedule 22 is to establish minimum safety standards to be followed in designing and constructing acceptable equipment for safe use in underground workings.

Safe operation of Diesel locomotives underground involves consideration of three possible hazards, namely, (1) toxic or objectionable gases discharged in the exhaust of the engine, (2) ignition of methane-air mixtures or of coal-dust air clouds by the engine or by electrical equipment, (3) fire hazards presented by the engine fuel oil and by coal dust or other combustible material in contact with or relatively close to the locomotive.

Operators of mines, particularly gassy coal mines, should know the major standards a Diesel engine is required to meet before it can be approved as permissible by the Bureau of Mines. The general requirements are quoted from Schedule 22, "Procedure for Testing Diesel Mine Locomotives for Permissibility, and Recommendations on the Use of Diesel Locomotives Underground," in Appendix A.

MAXIMUM LIMITS OF TOXIC GASES CONSIDERED PERMISSIBLE IN A WORKING ENVIRONMENT

Various private and governmental groups have determined the maximum limits of certain toxic gases considered to be permissible in a working environment. The different groups do not agree in all instances as to the maximum amount of some of the toxic gases that will not be injurous to persons working in that atmosphere; however, the standards established by all of the groups are feasible insofar as the operation of Diesel engines underground is concerned.

The United States Public Health Service, American Standards Association, Bureau of Mines, and the Health Departments of the various States are among the groups that have established maximum limits, and these limits, as applicable to the exhaust gases of Diesel engines, are discussed briefly.8/

Carbon Dioxide

The Bureau of Mines, in Schedule 22, "Procedure for Testing Diesel Mine Locomotives for Permissibility and Recommendations on the Use of Diesel Locomotives Underground," recommends that carbon dioxide content in the air of working places should not exceed 1 percent by volume. The United States

8/ Cooke, Warren A., Maximum Allowable Concentrations of Industrial Atmospheric Contaminants: Industrial Medicine, vol. 14, No. 11, 1945, pp. 936-946.

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Public Health Service and the States of California, New York, and Oregon adopted 0.50 percent by volume (5,000 parts per million) as the maximum limit; Utah adopted 0.555 percent (5,550 parts per million) as its maximum limit of carbon dioxide in a working environment.

Carbon Monoxide

The maximum concentration of carbon monoxide considered permissible in a working environment is 0.01 percent (100 parts per million). This standard is used by virtually all private, governmental, and State groups.

Oxides of Nitrogen

The maximum concentration of the oxides of nitrogen considered permissible in a working environment by most authorities is 25 parts per million (0.0025 percent). The exceptions are the Health Department of the State of New York, which establishes 40 parts per million as the maximum allowable concentration, and the State of Utah, which establishes the maximum limit as between 10 and 40 parts per million.

Aldehydes

The maximum concentration of aldehydes considered permissible in a working environment is based upon the comfort of the persons exposed to the atmosphere, not on the possible danger to persons working in that atmosphere, as is the case with other gases. It is so irritating to breathe that it is unlikely that men could continue to work in an atmosphere containing dangerous amounts. The standards are recommendatory in most instances and range from 5 to 20 parts per million, based upon formaldehyde, which is the basis of analysis.

The United States Public Health Service, American Standards Association, Bureau of Mines, and Health Departments of various States recommend a maximum limit of 10 parts per million for aldehydes; 20 parts per million is recommended as the maximum limit in Utah, and the Health Department of New York establishes 5 parts per million as a guide.[8/]

PROTECTIVE DEVICES USED ON THE DIESEL-ENGINE EXHAUST

The successful use of a Diesel engine underground or where men work in confined places depends largely upon positive and efficient devices that control or remove the toxic gases in the exhaust, which otherwise would be discharged into the surrounding atmosphere; very important is the maintenance of an adequate flow of pure air in the vicinity of the engines.

The successful use of a Diesel engine underground in a gassy coal mine, or where flammable material is present, is contingent not only upon the removal of the toxic gases from the exhaust but also upon the extinguishment of possible flame and reduction of ultra high temperatures that might ignite accumulations of methane or of explosive dust that might be present in some mine workings.

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Devices have been perfected that provide protection against some of the hazards of Diesel-engine exhaust gas and against possible ignition of methane-air mixtures; these devices have been in use for many years in European countries, and the considerable number of Diesel locomotives used underground in these countries indicates their effectiveness. Some European countries prohibit the use of trolley-type electric locomotives in gassy mines but permit the use of Diesel-powered and compressed-air locomotives in mines of the same class.

Protective devices now in use in European countries as well as some in use in the United States are described and discussed; the European devices are discussed in greater detail than the others because as late as February 1947 no Diesel engines have been tested for permissibility by the Federal Bureau of Mines.

EXHAUST-GAS PROTECTIVE DEVICES

Suitable means must be provided to protect persons against the effects of breathing exhaust gas from a Diesel engine before it can be operated safely underground. Devices designed to remove the objectionable constituents of the exhaust gas must be maintained in good mechanical condition at all times while the engine is in use, and certain specific operating procedures also must be carefully observed and maintained.

The device used to treat the exhaust gas usually is integral with the flame arrester on a Diesel engine designed for use in gassy coal mines. In metal mines, the flame arrester is less important and frequently is omitted, although this seems short-sighted. One of the functions of the device used to treat the exhaust gas is to cool the gas to less than the ignition temperature if the gas is capable of forming an explosive mixture with air; also, to prevent ignition of explosive methane-air mixtures. The temperature of the exhaust gas when it leaves the exhaust port in a 4-cycle engine[9/] ranges from 660° to 1,025°F.; it is slightly lower for a 2-cycle engine.

Mining regulations in some European countries require that the exhaust gas be cooled to a minimum of 160°F. before it is discharged into the atmosphere. Belgium permits the exhaust gas to be discharged into the atmosphere at a maximum temperature of 176°F.; the Bureau of Mines stipulates that the maximum temperature may not exceed 160°F.

The device, or scrubber, that treated the exhaust gas of the early Diesel locomotives used in nongassy coal mines in Germany was not combined with a flame arrester and consisted of a simple cast-iron box filled with stones, which were kept wet with a water drip; the exhaust gas passed through the box enroute from the engine manifold to the atmosphere; sometimes metal balls were substituted for the stones in the cast-iron box.

9/ Reed, Briand, The Diesel Locomotive Underground: Colliery Eng., May 1946.

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This method was not effective in reducing the quantity of the toxic constituents of the exhaust gas to the point required for safe operation.

Present-day devices for treating exhaust gas are designed to definitely lower the temperature of the exhaust gas, to absorb some of the toxic gases, to remove most of the smoke and odorous and irritating constituents, and to dilute the constituents remaining by admixing them with comparatively large quantities of air before the final exhaust gas is discharged into the atmosphere. The design of some Diesel engines manufactured in England provides for mixing the exhaust gas of the engine with 30 to 40 times its volume of fresh air before the final exhaust is discharged into the surrounding atmosphere. The constituents of the gas when absorbed by the water in the device form a very corrosive solution, and most European manufacturers are reported to use stainless steel to construct the device; this material has satisfactory resistance to the corrosive action of the solution.

The simplest type of device for treating exhaust gas consists of a bath of water placed between the engine exhaust ports and the pipe that discharges the exhaust gas into the surrounding atmosphere. Water seems to be the best available absorbent of the toxic and odorous constituents of exhaust gas; however, it now seems possible that the addition of certain chemicals increases the effectiveness of the water. The water bath also cools the exhaust gas and quenches any incandescent particles present. There are many variations in design of equipment to treat exhaust gas; one manufacturer installs two small water sprays in the pipe between the exhaust manifold and the scrubber; the sprays inject water upward, and the exhaust gas passes through the spray. The water from the spray collects and flows downward into the scrubber, thus replenishing its water supply. The sprays are linked with the fuel-pump mechanism, so that water is injected only while the engine is working; the water feed is controlled by the amount of fuel injected with the load on the engine. A thermostat on the side of the device prevents the temperature from exceeding 158°F. at that point; the thermostat shuts off the fuel intake to the engine when the temperature rises to or above 158°F., and in some designs of engines the brakes are applied automatically.

A device of new design to treat the exhaust gas, in use in the Netherlands, is described by M. G. Driessen.10/ The exhaust gas is cooled by water sprays, after which it passes through the exhaust pipe into the device. The device is provided with baffle plates, so that the exhaust gas must pass through the water several times, after which it passes through a screen box and thence to the atmosphere. The temperature of the final exhaust when leaving the screen box is usually not higher than 95°F. under severe working conditions. The water level in the device is maintained by the water sprays; if the water sprays stop functioning and the water in the conditioner becomes low, the higher temperature of the exhaust pipe actuates

10/ Driessen, M. G., A New Type of Diesel Locomotive for Use in the Dutch-State Coal Mines: Trans. Inst. Min. Eng., vol. 105, pt. 4, January 1946, 213 pp.

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a thermostat that shuts off the fuel supply to the engine. It is noteworthy that the temperature of the exhaust pipe causes the engine to stop automatically.

One type of Diesel engine-powered locomotive manufactured in the United States and used underground in a noncoal mining operation treated the exhaust gas as follows: The exhaust gas leaves the engine through a water-jacketed manifold and enters a pipe extending vertically from the manifold to the first exhaust cooling box placed near the front of the locomotive. A water spray enters the top end of the pipe and is supplied with water from a special tank by means of a small pump. The water from the spray travels downward through the pipe, in contact with the exhaust gas, to the first cooling box. The exhaust gas is discharged under water through a perforated pipe placed parallel to the bottom of the box. The exhaust gas passes to the top of the box, where a perforated and a solid baffle are interposed to stop water spray. The exhaust gas leaves the first cooling box through another pipe; this conducts it to a second cooling box on the opposite side of the locomotive. This box separates the water spray from the exhaust gas by means of a series of baffles. The two cooling boxes are connected by means of an equalizing pipe to maintain the same water level in both boxes. The exhaust gas passes through an exhaust labyrinth, which removes the soot and prevents propagation of flame. The exhaust gas passes into a fan chamber and is mixed with air delivered by the fan through the cooling radiator and is then discharged into the atmosphere. A diagrammatic sketch of the method of handling the exhaust gas is shown in figure 2.

FLAME PROTECTIVE DEVICES

A Diesel engine can be operated with safety in an underground gassy mine only if effective and positive protective devices are installed to prevent ignition of possible explosive mixtures of gas and air or dust and air that may be present. These protective devices must be maintained in serviceable condition at all times while the engine is in operation.

Flameproof electrical equipment has been defined as follows: "Electrical apparatus is said to be flameproof when it is incapable, in its normal working, of igniting gas-air mixtures in the surrounding air." The apparatus not only must pass no flame through the joints but must be able to withstand any explosion of a gas-air mixture that may be present within. To be flameproof, a Diesel engine must pass the same type of tests as electrical apparatus; not only must the flame be prevented from passing out of the gas conditioner, but there must be no risk that an interior explosion will penetrate outward either through joints or by a rupture of the containing structure resulting from high explosion pressure.

The British Mines Department stipulated in the original tests of Diesel engines for underground use in coal mines in Great Britain, "although it could be argued that flame could not pass out from the final exhaust through the conditioner, or through the air-inlet filter, yet if by chance flame was formed in the inlet or exhaust manifolds and the atmosphere in those

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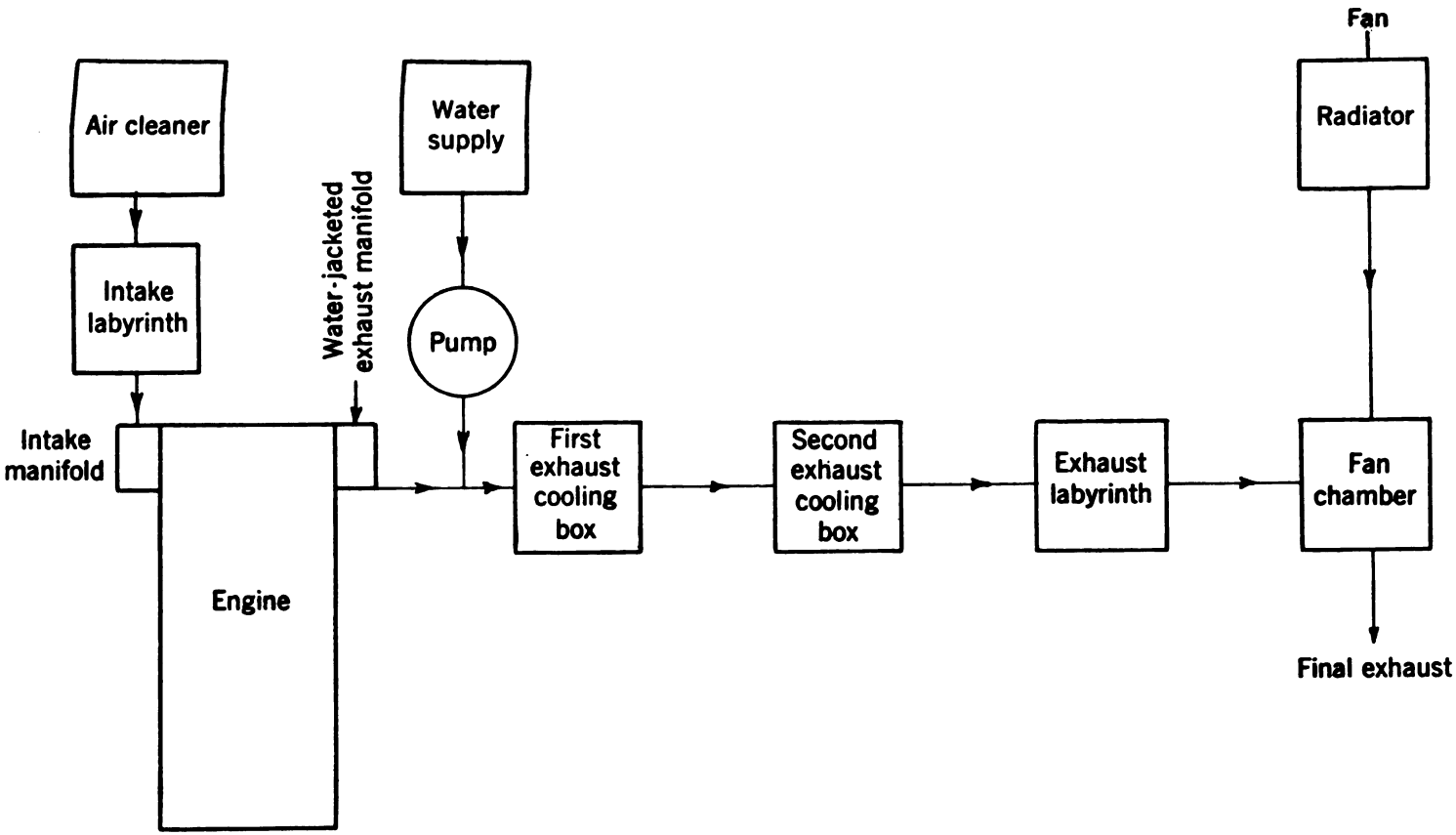

Figure 2. - Diagrammatic flow of exhaust gas from engine to final exhaust.

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pipes happened to be of an explosive nature, a severe explosion could occur and cause a high pressure and a propagating flame outwards."[11] The equipment was required to be made so that in case of an explosion within the engine, flame could not reach the atmosphere. In practice this meant that the cylinder heads, injector joints, valve stems, valve covers, manifold joints, and the entire intake and exhaust systems had to be made flameproof; furthermore, the inlet and exhaust orifices were required to be of the type that would stop absolutely the most penetrating kind of flame. These requirements are responsible for much of the high initial cost of flameproof Diesel locomotives.

There are many types and designs of flame arresters for Diesel engines, but the most common is the labyrinth type, which consists essentially of a multiple metal-plate device that provides narrow passages for the escaping exhaust gases. It is usually held that flame arresters should be placed in both the exhaust outlet and in the air intake; the flame arrester in the air intake prevents the propagation of flame if an explosive methane-air mixture is drawn into the cylinders and should be ignited; some experts question the necessity for having rigid flame-arresting devices in the intake.

The labyrinth flame arrester installed on an American-manufactured Diesel engine for underground use is described as follows: The labyrinth consists of approximately 250 brass disks 4-31/32 inches in diameter and 0.031 inch thick, spaced 0.043 inch apart and attached to a common shaft at their centers. These plates may be rotated by turning the shaft. Interposed between the rotating plates are fixed plates 0.032 inch thick and of such shape that they occupy slightly less than half of the spaces between the rotating plates. These fixed plates are intended to act as scrapers to remove soot accumulations when the rotating plates are turned. Openings in the compartment containing the labyrinth permit inspection.

In continental Europe, the usual metal-plate labyrinth provided narrow passages about 0.5 millimeter wide and about 5.0 millimeters high for the inlet and exhaust. Such a labyrinth has a cooling effect sufficient to prevent the passage of flame from the interior of the surrounding atmosphere. It is also necessary to prevent possible sparks from unburned oil from reaching the outside; therefore, the exhaust gases are cooled, and any sparks are extinguished with a water spray in the exhaust pipe. Sometimes the exhaust gas is compelled to sweep over a water surface and to penetrate through layers of pebbles before reaching the labyrinth.

In the Netherlands, the metal-plate type of labyrinth flame arrester has been used, but on the new type of Diesel locomotive described by Driessen,[12] another type is used because of the high back pressure caused by the older arresters. The plates are replaced by so-called "Raschig" rings of porcelain, which offer very little resistance to the exhaust gases and can contain much water owing to their large surface and hygroscopic qualities.

11/ See footnote 9.
12/ See footnote 10.

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In Great Britain, metal-plate type labyrinths are used on the intake and exhaust; the labyrinths are interchangeable and may be used on either the intake or exhaust. The labyrinths are made of stainless steel, and the corrosive gases have little effect upon them. The exhaust labyrinths are changed for clean ones at the end of each shift; the entire arrester is changed as a unit, and the used labyrinth is taken apart and cleaned. The labyrinth flame arrester used by one British manufacturer is described as follows: "It consists of a series of stainless-steel plates 2-1/4 inches long, 2 inches deep, and 0.009 inch thick assembled within a rectangular framework bolted to the inlet and exhaust openings, respectively. The plates are machined for a length of 2 inches to give, when assembled, a grille with vertical gaps 0.016 inch wide and 2 inches deep. These gaps afford the necessary release to allow adequate air inlet and gas exhaust with very low back pressure and at the same time maintain the flameproof character of the unit."

Flame arresters of whatever type have a tendency to clog with soot and particles of unburned oil; this decreases the effectiveness of the engine by increasing the back pressure. The arresters must be cleaned or changed often enough to prevent this; otherwise, the engine does not function correctly.

OPERATION OF A DIESEL ENGINE IN OTHER THAN NORMAL AIR

The quality of air ventilating places where a Diesel operates is of utmost importance; the atmosphere in underground mines frequently contains more than normal amounts of carbon dioxide and less than normal amounts of oxygen. Also, particularly in coal mines, methane may be liberated from the coal or surrounding strata and must be considered when calculating the ventilating requirements before a Diesel engine is placed in service.

Normal dry air is considered to be composed of

	Percentage by volume
Oxygen	20.93
Nitrogen*	79.04
Carbon dioxide	0.03
	100.00

*Includes small amounts of numerous inert gases.

The mining law and regulations of one State require that mine air contain not less than 19-1/2 percent of oxygen, but most mining States do not specify the minimum percentage of oxygen permitted in the air where men work. The Bureau of Mines recommends that mine air contain at least 20 percent oxygen and not more than 1 percent carbon dioxide.

Regulations in several European countries specify the maximum content of methane permitted in mine air in which Diesel locomotives may operate. The regulations are not uniform and are excerpted below:

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Great Britain. - The ventilating air entering a road on which a Diesel locomotive is operating shall not contain more than 1 percent methane; the general body of air in the roads themselves must not exceed 0.5 percent methane when the locomotive is operating.

France. - The ventilating air in which a Diesel locomotive is permitted to operate shall not contain more than 0.5 percent methane, and the air in the passages leading to a haulageway on which a Diesel locomotive operates shall not contain in excess of 0.7 percent methane.

Germany. - Diesel locomotives operate in intake air. An exception was made in one recorded instance in the Saar district; a Diesel locomotive was permitted to operate in return air containing 0.25 percent methane.

Sardinia. - Diesel locomotives operate in intake air.

Spain. - Diesel locomotives operate in intake air.

The coal-mining laws of various States specify the maximum allowable percentage of methane in the return air, ranging from 0.50 to 1.50 percent. The Bureau of Mines recommends that not more than 0.50 percent of methane be permitted in return air from any split in the ventilating current of a coal mine.

It should be remembered that whenever a Diesel engine operates in an underground atmosphere containing less than 20.93 percent oxygen, the air:fuel ratio at a given speed and fuel input will be greater than when the engine operates in normal air.

EFFECT OF EXHAUST GASES IN THE INTAKE AIR

The exhaust gases of a Diesel engine consist largely of carbon dioxide, oxygen, and nitrogen, with minor percentages of other gases, some of which are toxic. The atmosphere in which a Diesel engine operates is contaminated with the exhaust gases unless the ventilating air current dilutes and carries them away.

The effect of exhaust gases in the intake of a Diesel locomotive has been studied by engineers of the Bureau of Mines,[13] and the following discussion briefly outlines some of the facts determined in the studies:

Hot exhaust gases were mixed with the intake air of a four-stroke-cycle Diesel engine, and the results indicated a marked increase in carbon monoxide in the exhaust gases, a decrease in the oxides of nitrogen, and no significant effect upon aldehydes. The increase in carbon monoxide was greater at higher air:fuel ratios and was caused partly by the increase in

13/ Berger, L. B., Elliott, M. A., Holtz, J. C., and Schrenk, H. H., Diesel Engines Underground. II. Effect of Adding Exhaust Gas to Intake Air: Bureau of Mines Rept. of Investigations 3541, 1940, 18 pp.

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air:fuel ratio and partly by the decrease in oxygen concentration resulting when exhaust gas was added.

The tests show that increases in the air:fuel ratio and decreases in the oxygen content cause the greatest increase in carbon monoxide at the higher air:fuel ratios. In the lower air:fuel ratios, in which the excess air was always greater than approximately 50 percent, the carbon monoxide content was essentially unchanged by the addition of exhaust gas to the intake.

Carbon dioxide in the intake has a marked effect upon the operation of a Diesel engine; it causes the amount of carbon monoxide in the exhaust gases to increase, as well as the amounts of aldehydes and other irritants. The following observations were made regarding the air in the tunnel in which a Diesel locomotive was operating.14/

> When the concentration of carbon monoxide is 0.01 percent and that of carbon dioxide is 0.3 percent, visibility is poor to bad, and the aldehydes and other irritants are obnoxious after a relatively short exposure.
>
> When a Diesel locomotive is run until the concentration of carbon monoxide is 0.01 percent and that of carbon dioxide is approximately 1 percent, visibility is blanked out and the odors are sickening. When an ordinary Diesel truck is used, this condition is achieved with 0.003 to 0.005 percent carbon monoxide and 0.3 percent carbon dioxide.

The tests and observations of Diesel-engine operations by the Bureau of Mines engineers emphasize the importance of maintaining at all times the oxygen and carbon dioxide content of the surrounding atmosphere within specified limits, because decidedly hazardous conditions result when the intake air contains more than 1 percent carbon dioxide or less than 19 percent oxygen. Some authorities believe that Diesel engines should not be permitted to operate underground in an atmosphere containing less than 20 percent oxygen or more than 0.5 percent carbon dioxide. It is important to remember that an atmosphere containing approximately 1 percent carbon dioxide may not be dangerous under ordinary conditions, but that a Diesel engine cannot be operated safely when the atmosphere contains more than 1 percent carbon dioxide; in fact, Diesel engines should be operated in practically normal air.

EFFECT OF METHANE IN THE INTAKE AIR

The atmosphere in many coal mines contains at least small amounts of methane, and the effect of this gas upon the operation of a Diesel engine is important if the engine is to be used where this gas may be present.

14/ See footnote 5.

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Before Diesel locomotives were permitted to operate in gassy coal mines in Europe, the various countries conducted independent tests by running the engines in methane-air mixtures and noting the results and, in some instances, analyzing the exhaust gas.

Early German experiments demonstrated that ignition of an explosive methane-air mixture could be obtained from either the intake or exhaust of a Diesel engine unless flame arresters were installed on both the intake and the exhaust. It was also demonstrated that Diesel engines operating in 5 to 9 percent methane-air mixtures continued to run after the fuel supply had been shut off.

French experiments led the authorities to conclude that the Diesel engine is almost as good a methane detector as a flame safety lamp, because as the percentage of methane in the atmosphere increased the sound made by the engine changed.

In Belgium, it was found in tests that the rotational speed of the engine kept rising and falling in methane-air mixtures and the engine had a tendency to overspeed, but in some cases it actually stopped after a drop in speed. The variations in speed are not a source of danger, as the variations begin before the methane concentration is at the lowest flammable limit. Tests have shown that the methane drawn into the cylinders is not entirely burned and that methane may be present in the exhaust pipe of the engine.

The Bureau of Mines conducted tests of Diesel engines operating in a natural gas-air mixture[15] particularly to determine the effect of methane in the intake air upon the exhaust gas.[16] In every test it was found that the presence of natural gas in the intake air of a Diesel engine caused the concentration of carbon monoxide in the exhaust to increase, as compared with operation in normal air; the aldehydes increased greatly, but the amount of oxides of nitrogen did not increase significantly when the concentration of natural gas in the intake was less than 1 percent. There was slightly less carbon dioxide in the exhaust gas when natural gas was present in the intake air, but the decrease was not sufficient to affect the quantity of ventilation required. During some of the tests the smoke in the exhaust increased, but this was not significant; in general it was concluded that the presence of natural gas in the intake had no effect upon smoke production unless it caused the air:fuel ratio to approach or exceed the chemically correct value.

The tests conducted by the Bureau of Mines emphasized the importance of maintaining low concentrations of combustible gas in the atmosphere in which a Diesel engine operates.

15/ The natural gas used in conducting the tests contained approximately 85 percent methane; the remainder consisted of ethane, small quantities of higher hydrocarbons, and about 1 percent of nitrogen.

16/ See footnote 7.

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INFORMATION ABOUT EUROPEAN DIESEL LOCOMOTIVES

Diesel-powered mine locomotives for use in underground coal mines have been developed to a higher level of safety in Europe than in the United States; this is due to the large number of such locomotives in use in the various countries and the relatively long time they have been used in coal mining, together with the fact that in the United States numerous State and Federal agencies are opposed to the use of internal-combustion engines underground.

The size and power of Diesel mine locomotives have been increased in the last few years, and reports indicate that the latest types manufactured can be considered as competitive in size and performance with any other type of mine locomotive in service.

Great Britain

Diesel locomotives for use in surface plants have been manufactured in Great Britain for a number of years but were not equipped with exhaust-gas protective devices other than flame arresters. An 80-horsepower Diesel locomotive was used at the Woolwich Arsenal and was chosen for this service because of its safety while working in and around flammable materials. Many Diesel locomotives were built for metalliferous mines, where exhaust-gas protective devices were more important than flameproof operation, as in gassy coal mines.

Diesel engines for use in gassy coal mines are required to meet the Buxton certificate requirements (see Appendix B), which are similar to the proposed requirements for permissibility as written in Schedule 22 of the Bureau of Mines.17/ These requirements appreciably increase the cost per brake horsepower of the engine, but they are considered essential for safe operation underground in gassy mines.

Flameproof Diesel locomotives now manufactured in Great Britain for use underground in coal mines range in size as follows:

Brake horsepower	Weight, tons	Purpose
Less than 20	2.5	Replaces mules
More than 20	4 to 5	Gathering
25	7	Gathering
50	10	Man trips and coal
50	10	Coal only
100	15	Mainline haulage
200	20	Mainline haulage

The device for removing the toxic gases from the exhaust is made of stainless steel to resist the corrosive action of the toxic gases in solution

17/ Bureau of Mines, Procedure for Testing Diesel Mine Locomotives for Permissibility and Recommendations on the Use of Diesel Locomotives Underground: Schedule 22, 1944, 31 pp.

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The flame arresters, called flame traps by some authorities, are designed to permit a locomotive to operate 24 hours continuously without clogging. Flame arresters are placed in both intake and exhaust, and can be removed and new ones installed in about 5 minutes. The entire engine meets the Buxton-certificate requirements, and it is required that flame cannot pass to the surrounding atmosphere under any circumstance, including an explosion in the exhaust pipe.

A typical exhaust-gas analysis taken from actual records is as follows:

	Percent
Oxygen	17.14
Nitrogen	80.34
Carbon dioxide	2.32
Carbon monoxide	0.031
Combined other gases	0.20

The Regulations of the Ministry of Mines require the carbon monoxide content to be less than 0.5 percent, and in practice it has not been difficult to keep it so. The amount of carbon monoxide in the exhaust is not controlled by the exhaust conditioner, but by combustion of the fuel within the cylinders of the engine.

Automatic safety devices are incorporated in the exhaust conditioner to shut off the supply of fuel and apply the air brakes in the event the level of the water in the exhaust conditioner falls below a certain point.

Plans are being developed to use two 100-horsepower units connected in tandem and operated by one engineer instead of the larger 200-horsepower unit. Tests indicate that the tandem unit will have a tractive effort of about 16,000 pounds, and the weight of the units will be better distributed.

The first two British manufacturers of Diesel engines for underground use in gassy coal mines to meet the Buxton-certificate requirements were the Hunslet Engine Co., Ltd., and Ruston & Hornsby, Ltd. Specifications of two of the popular smaller Diesel locomotives manufactured by the Hunslet Engine Co., Ltd., are given below:

Specifications of Diesel mine locomotives

	25 h.p.	50 h.p.
Typical track gage	2'0"	2'6"
Diameter of coupled wheels	1'8"	2'0"
Wheel base	3'0"	4'0"
Height over all	5'0"	5'0"
Width over all	3'4"	3'11"
Length over all, without coupling	11'3-1/2"	13'0"
Maximum power and speed of engine	25 h.p. at 1,300 r.p.m.	50 h.p. at 1,300 r.p.m.

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Specifications of Diesel mine locomotives (cont'd.)

	25 h.p.	50 h.p.
Speed:		
1st gear	3.25 m.p.h.	3.00 m.p.h.
2d gear	5.05 m.p.h.	4.66 m.p.h.
3d gear	8.56 m.p.h.	7.9 m.p.h.
4th gear	12.46 m.p.h.	12.25 m.p.h.
Fuel capacity, gallons	7	13
Weight, in working order	4 tons 11-1/2 cwts.	8 tons 10 cwts.
Maximum axle load	2 tons 7 cwts.	4 tons 6 cwts.
Tractive effort:		
1st gear	2,450 pounds	5,310 pounds
2d gear	1,580 pounds	3,420 pounds
3d gear	930 pounds	2,020 pounds
4th gear	640 pounds	1,300 pounds
Ratio, adhesive weight divided by tractive effort	4.2 to 1	3.6 to 1
Minimum radius curve recommended	30 ft.	30 ft.
Weight per yard of lightest rail recommended	14 pounds	20 pounds

The load that any locomotive can start and haul depends on the grade of the track and frictional resistance of that load. The following tables show the rated performance of the engines described above:

Loads Diesel locomotives will haul, based upon 18 lb./ton starting resistance and 12 lb./ton running resistance, tons

25-horsepower Hunslet mines type locomotive

Speed, m.p.h.	Level	1 in 200	1 in 100	1 in 50
3.25	131	79	56	34
5.05	126	63	42	23
8.56	73	35	23	12
12.46	49	24	14	7

50-horsepower Hunslet mines type locomotive

3.00	286	173	124	76
4.66	276	139	91	52
7.9	160	79	50	27
12.25	100	48	29	14

Figure 3 shows a 50-horsepower, flameproof, mines-type, Diesel locomotive manufactured by the Hunslet Engine Co., Ltd. This locomotive is used for gathering and for hauling man trips. Figures 3a and 3b show the 100-horsepower locomotive. Figure 4 shows a 24-passenger car used for man trips. These cars are equipped with air brakes, as can be seen in the illustration.

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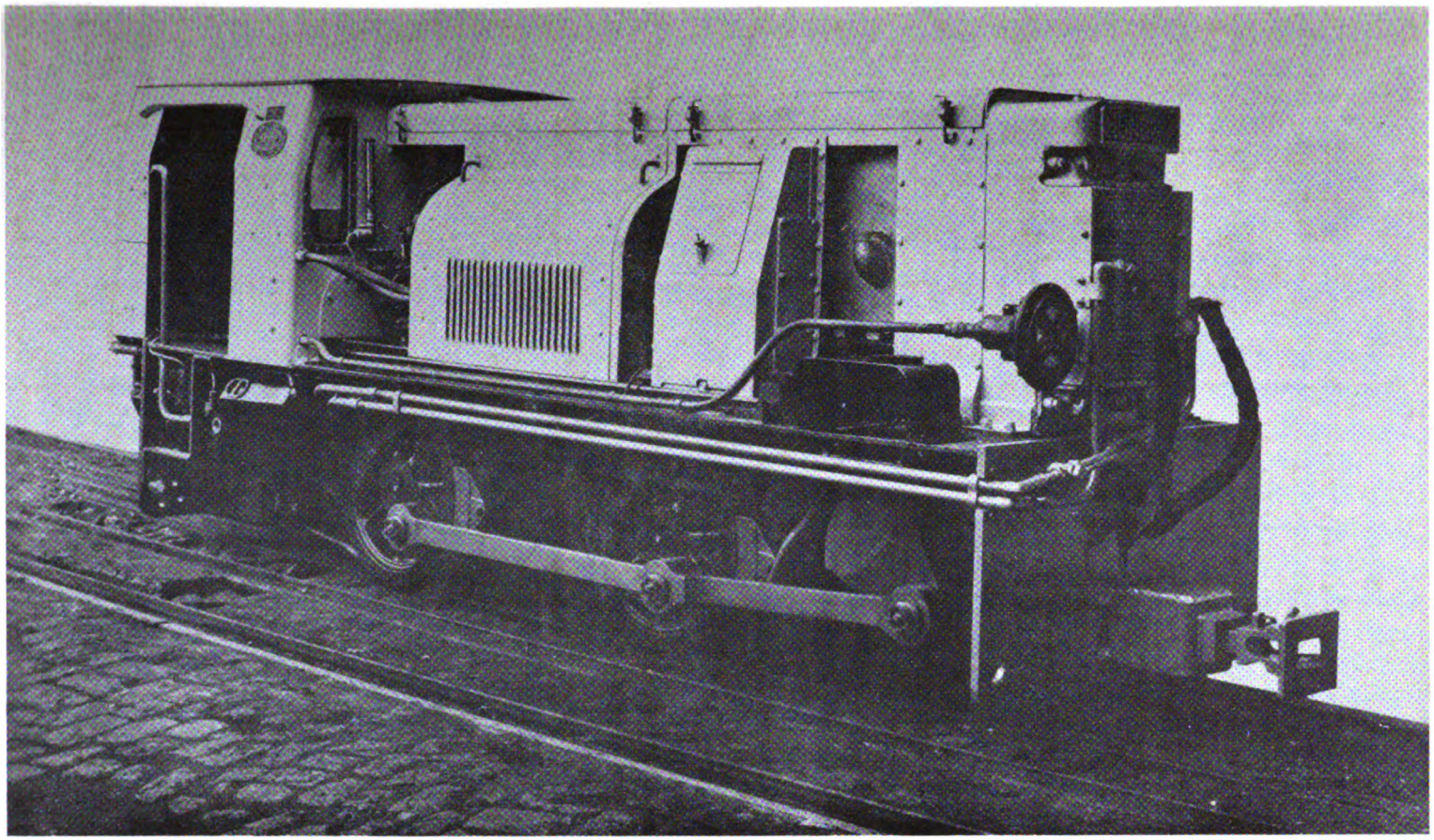

Figure 3. - "Hunslet" 50 h.p. flameproof mines type Diesel locomotive.

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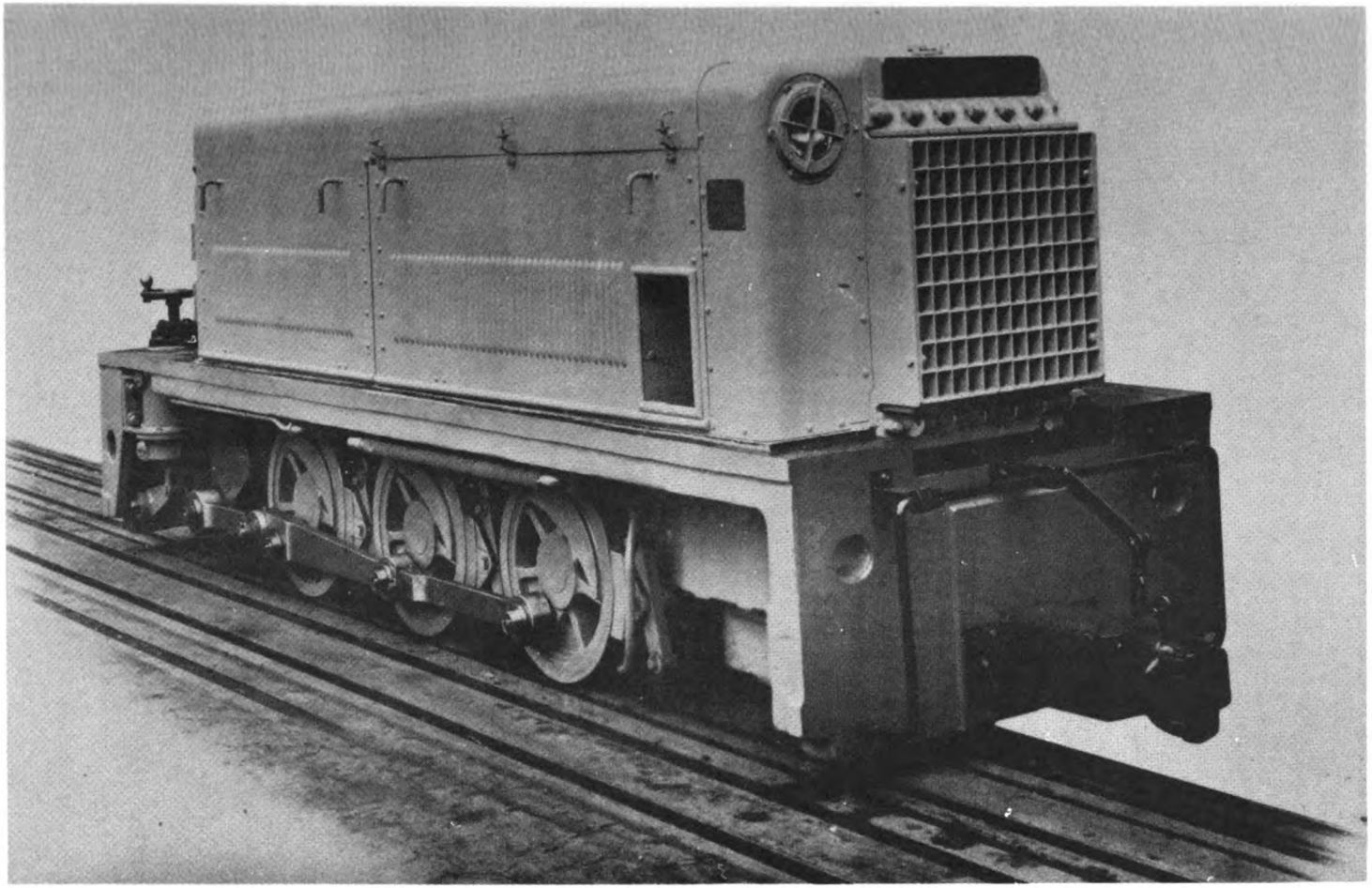

Figure 3-A. - "Hunslet" 100 h.p. heavy duty flameproof Diesel locomotive for coal haulage and man riding duty.

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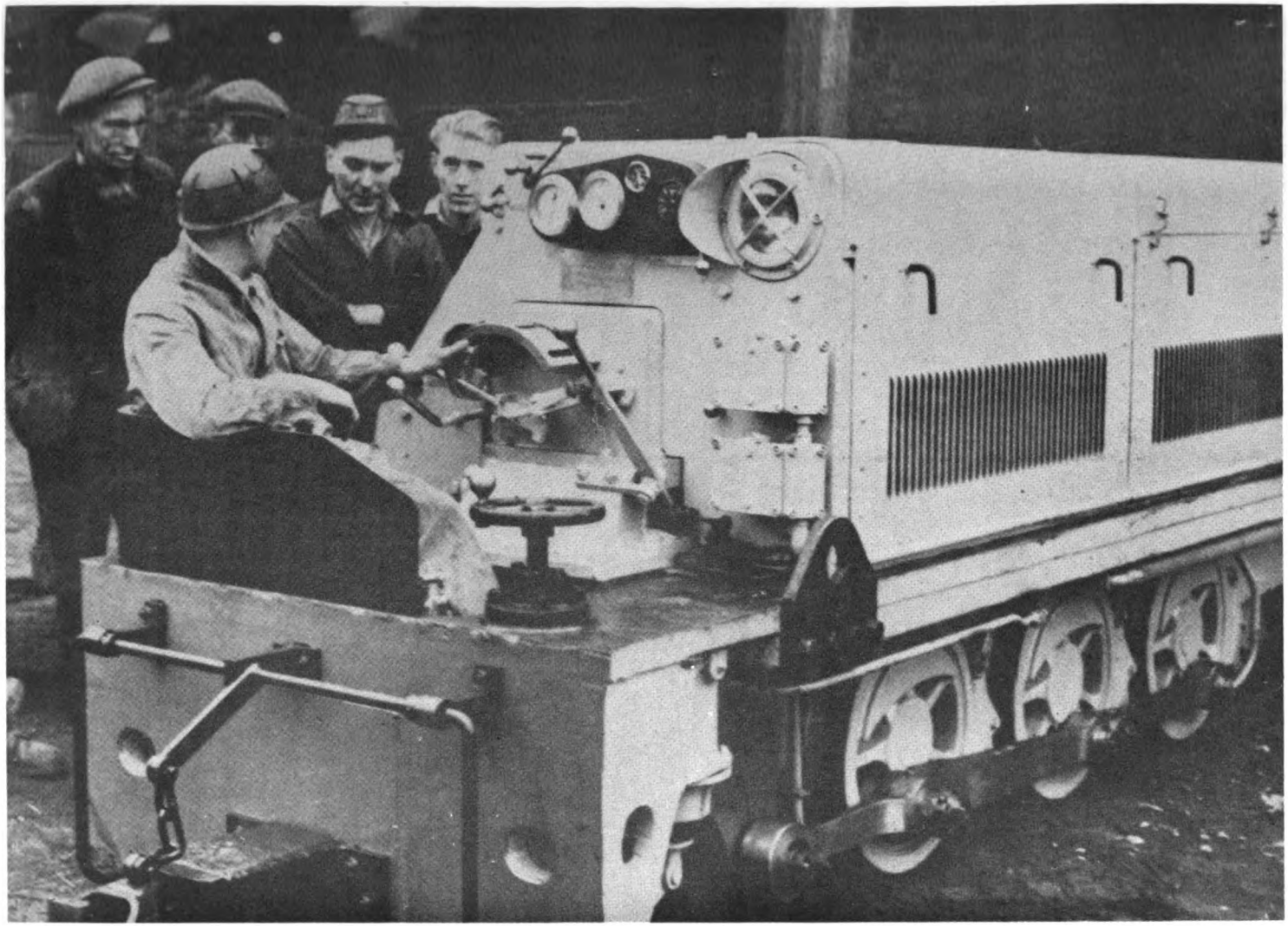

Figure 3-B. - "Hunslet" 100 h.p. heavy duty flameproof Diesel locomotive for coal haulage and man riding duty.

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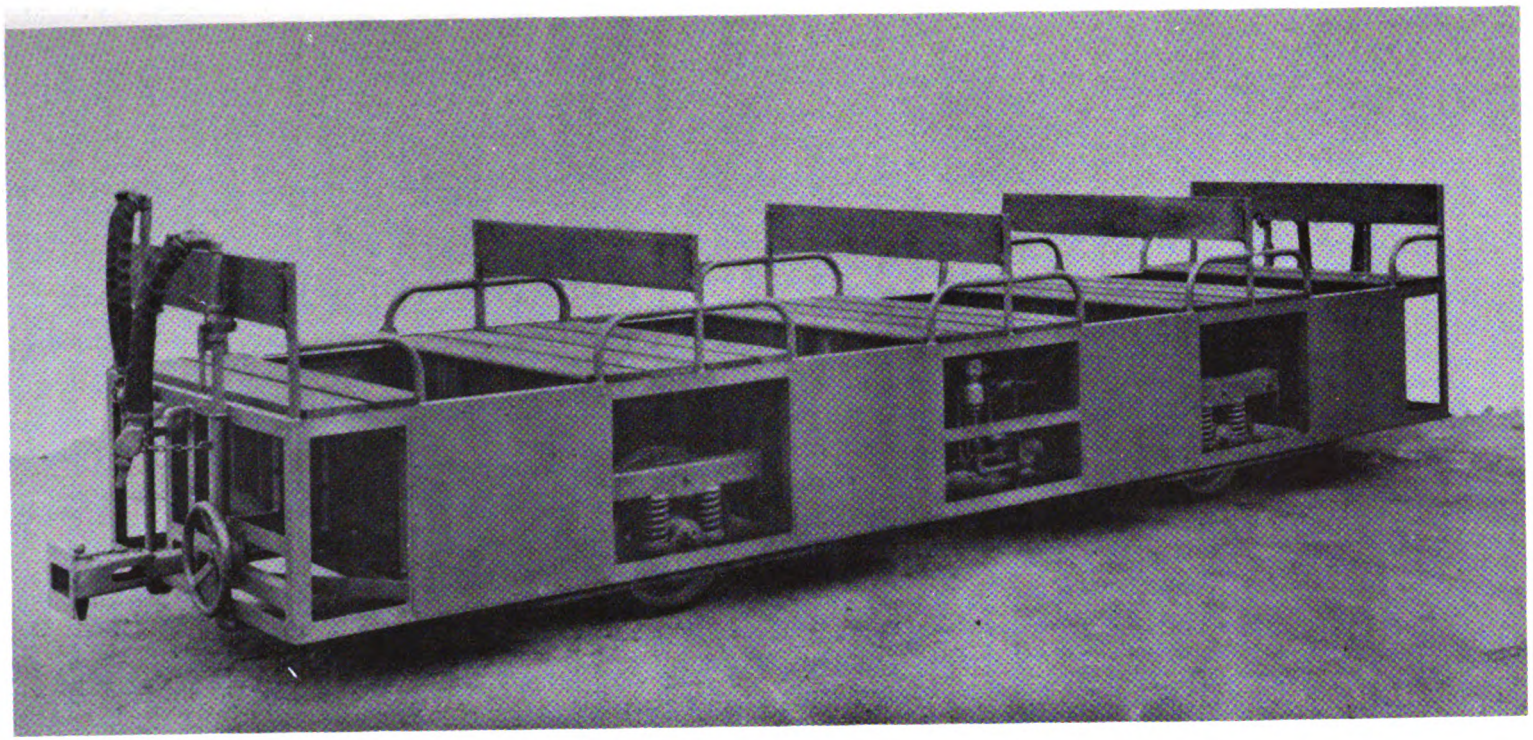

Figure 4. - The "Hunslet-Wickham" 24-passenger man-riding car.

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The Diesel locomotives used in the underground gassy coal mines of Great Britain are subjected to more stringent regulations than in any other European country, and for this reason these locomotives have been developed to their present stage of safety and efficiency...

Some authorities believe that Diesel mine locomotives will displace many, if not all, of the rope haulage installations in the British coal mines.

Netherlands

A new type of Diesel mine locomotive has been developed in the Netherlands for use primarily in the Dutch State coal mines. It is designed to replace the present compressed-air locomotives hauling coal to the mine shafts. The locomotive is described by M. J. Driessen.18/

The design of the new locomotive eliminates crankshafts, connecting and coupling rods, and drives the wheels by means of a worm and worm wheel. There are no external moving parts except the locomotive wheels. The maximum output of the engine is rated at 78 horsepower at 1,700 r.p.m., but the speed is reduced for heavy duty to 1,300 r.p.m. and the horsepower to 56 in order to obtain an underrated load of the engine under all conditions.

The Diesel engine transfers its motion to the 2-speed forward and reverse gear box through a hydraulic coupling of the traction type. This fluid coupling has proved successful by simplifying the control of the locomotive and by reducing the number of gear changes. The fluid coupling permits the Diesel engine to run up to about 30 percent of maximum speed before full engine torque is transmitted to the gear box. The torque is built up by gradually increasing the speed of the engine; the coupling itself does not require any control. As soon as the starting torque overcomes the resistance of the locomotive, the slip in the fluid coupling falls quickly, causing smooth starting of the locomotive. In case the starting resistance of a heavy train is greater than the Diesel engine is capable of developing, the engine will keep running at the full torque stalling speed, and the fluid coupling will prevent the engine from stopping.

The driving shaft of the gear box is provided with universal couplings to drive the worms and worm wheels, which are floating on the main locomotive axles, and both axles are driven without connecting rods. The frame of the locomotive is built outside of the wheels, with resultant broader and more stable construction. Inspection has shown wear on the worm wheels to be very small (less than 0.004 inch) after a working period of more than 1 year of 3 shifts a day.

A driver's cab is placed at each end of the locomotive, so that the engineer can always face in the direction the locomotive is running and thus have a better view of the track.

18/ See footnote 10.

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Specifications of the new type Diesel locomotive in the Netherlands

Diesel motor:	
Number of cylinders	6
Speed	1,300 r.p.m.
Power, reduced to	65 h.p.
Power, maximum	85 h.p.
Cylinders:	
Diameter	4-1/4 inches
Stroke	6 inches
Maximum torque	259 foot-pounds
Force at locomotive hook (drawbar pull):	
At normal speeds:	
1st acceleration, 4.2 m.p.h.	3,750 pounds
2d acceleration, 9.0 m.p.h.	1,540 pounds
Speed for man-riding (not used in State mines):	
1st acceleration, 5.1 m.p.h.	2,420 pounds
2d acceleration, 12.5 m.p.h.	1,100 pounds
Load: 60-80 cars of 1,000 liters capacity (approximately 36 cu. ft.) about 1 ton each.	
Locomotive:	
Rail gage	23.6 inches
Wheel gage	46 inches
Wheel diameter	20 inches
Weight	23,100 pounds
Length, over all	17'6"
Width, over all	3'6"
Height, over all	5'3"
Fuel tank capacity, gallons	20
Fuel consumption of locomotive working 3 shifts daily in 24 hours	13.3 to 14.7 gallons
Water consumption, gallons per hour	16 to 17
Minimum track curve, radius	50 foot
Brakes	Hand-operated

STATISTICS ON DIESEL LOCOMOTIVES IN EUROPEAN MINES

Diesel mine locomotives have been used with considerable success in continental Europe for at least 18 years, but the extent to which they are used is not well known in this country. Most of the Diesel locomotives in European underground mines are used for main-line haulage units, although numerous smaller units are used for gathering purposes. Statistics are not available for all European countries, but table 2 gives a classification of mine locomotives according to type of power in three countries prior to the war.

Diesel locomotives were first permitted in underground gassy coal mines in England in 1939, and more than 40 of this type of haulage unit were reported to have been operating in British coal mines in 1946. Statistics showing the number of Diesel locomotives in underground mines in Holland and Poland are not available, although it is known that many are used.

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TABLE 2. - Mine locomotives used in underground coal mines in some European countries

Country	Year	Type of power and number in use			
		Diesel	Compressed Air	Electric	Gasoline
Germany	1938	602	1,199	1,801	81
Belgium	1939	114	18	33	19
France	1935	357	123	250	?

In 1937, France had 380 mine locomotives in the underground coal mines; in four mining districts that produced 80.7 percent of the domestic coal only 22 electric locomotives were used, whereas 345 Diesel and 123 compressed-air type were in operation.

Table 3 shows the number of mine locomotives operating in Germany in 1938, classified by type of power and mining district.19/

TABLE 3. - Mine locomotives in German underground coal mines in 1938

Main-line haulage locomotives

District	Diesel	Electric		Compressed Air	Total
		Trolley	Cable Reel		
Ruhr	279	1,163	33	673	2,148
Aachen	73	27	5	37	142
Upper Silesia	9	237	0	0	246
Lower Silesia	41	31	0	0	72
Saxony	2	20	0	18	40
Saar	129	16	0	125	270
	533	1,494	38	853	2,918

Gathering locomotives

Ruhr	61	0	259	342	662
Aachen	1	0	0	4	5
Saar	4	0	0	0	4
Upper Silesia	1	0	7	0	8
Lower Silesia	2	0	3	0	5
Saxony	0	0	0	0	0
	69	0	269	346	684

The statistics show that 18 percent of all main-line haulage locomotives in German underground mines in 1938 were Diesel-powered; however, the Saar and Aachen coal fields used approximately 50 percent, whereas the Ruhr district used 18 percent.

19/ East, J. H., Jr., Operating Diesel Locomotives Underground in European Mines: Bureau of Mines Inf. Circ. 7378, 1946, 13 pp.

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The German national policy prior to the war of not using materials that had to be imported prevented extension of the use of Diesel engines, as fuel oil is not produced in substantial amounts in Germany.

No trolley locomotives are used for gathering in German coal mines; the mines generally are gassy, and the gathering locomotives are limited to electric cable-reel, compressed-air, and Diesel types because of the ignition hazard. It is noticeable that the Germans consider the Diesel suitable for gathering purposes, this being especially true of the Ruhr.

The average horsepower of all types of main-line locomotives used in Germany is about the same; the electric trolley locomotives average 41 horsepower, whereas the Diesel locomotives average 39 horsepower. The Diesel-powered gathering locomotives average 11 horsepower, and the electric cable-reel types average 9 horsepower.

In Belgium, the mine locomotives in use in underground coal mines in 1939 were classified as follows:

Type of power	Number of locomotives	Percent of total
Diesel	114	62.0
Gasoline	19	10.3
Compressed-air	18	9.8
Electric	33	17.9
	184	100.0

In France, the mine locomotives working in underground mines in 1935 were classified as follows:

Type of power	Number of locomotives	Percent of total
Diesel	357	48.9
Compressed-air	123	16.8
Electric:		
Trolley	103	14.1
Storage-battery	147	20.2
	730	100.0

Many mine officials in continental Europe prefer to use Diesel or compressed-air locomotives rather than electric trolley types because of the danger of ignition of gas accumulations by the arc of the trolley. Most of the main-line haulage is done on intake air, and an excess of ventilation is relied on to dilute and carry away the exhaust gases of the Diesel locomotives. Exhaust-gas conditioners are required in virtually every country, but the emphasis is on excess ventilation of the haulageway. It is noticeable that in Belgium 62 percent and in France 48.9 percent of the mine locomotives were Diesels. Electric locomotives constituted only 17.9 percent of those in use in Belgium, and trolley locomotives used in France constituted only 14.1 percent of the total mine locomotives in operation.

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SOME DESIRABLE FEATURES IN DIESEL LOCOMOTIVES FOR USE IN AMERICAN MINES

Some of the desirable features for Diesel mine locomotives intended for use in underground mines in the United States are discussed below. Most of these features are incorporated in the Diesel mine locomotives manufactured in England and Continental Europe and are considered to be necessary for safe operation, and many of them are included in the tests for permissibility determined by the Bureau of Mines and issued in Schedule 22, "Procedure for Testing Diesel Mine Locomotives for Permissibility, and Recommendations on the Use of Diesel Locomotives Underground."

Metal and nonmetallic mines usually do not require flameproof Diesel mine locomotives for use underground, as they do not, as a rule, have explosive atmospheres; but such locomotives are desirable in many mines because of possibility of fires and explosions of gas or explosives. Diesel mine locomotives used in underground coal mines should be flameproof in order to prevent possible ignition of any gas accumulations or of dust clouds.

1. The exhaust-gas conditioner should be large enough to cool the exhaust gas to less than 180°F. under the most severe working conditions.

2. A device should be installed to stop the engine automatically if the temperature of the exhaust gas exceeds 180°F. at the point of discharge from the cooling system.

3. A chemical method of absorbing the aldehydes and oxides of nitrogen in the exhaust gas is desirable. Water absorbs the aldehydes, but the water in the air conditioner must be changed frequently enough to prevent it from becoming saturated and losing its absorbent qualities.

4. A chemical method of converting carbon monoxide in the exhaust gas to carbon dioxide or absorbing the carbon monoxide is desirable; the methods that have been tried experimentally thus far have not been successful.

5. The exhaust-gas conditioner should function efficiently for at least one shift without requiring attention such as changing the water or adding chemicals.

6. The exhaust gas, after cooling, should be diluted with air before being discharged into the atmosphere. This reduces the hazard from toxic gases to persons in the immediate vicinity of the mine locomotive.

Flame Arrester

7. Flame arresters should be placed on both the air intake and the exhaust of a Diesel engine that is to be used underground in coal mines.

8. The flame arresters should be so designed that they can be cleaned or replaced quickly and easily.

9. The materials used in the manufacture of flame arresters should be noncorrosive.

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Miscellaneous

10. Diesel mine locomotives should be equipped with at least two and possibly three independently operated brakes. Air brakes are desirable as well as hand-operated brakes.

11. The spring suspension of the locomotives should be designed to provide maximum stability on rough, uneven track. Many mine tracks are poorly maintained, with resultant low joints and uneven track, which may cause derailment.

12. The Diesel mine locomotives now in use are too high above the rail for use in many "low" coal mines. A locomotive designed for service in relatively low coal is desirable.

USE OF DIESEL MINE LOCOMOTIVES IN THE UNITED STATES

Diesel locomotives are used underground in the United States, but only to a very limited extent. In November 1946, insofar as information was available, only four Diesel mine locomotives were operating underground in the United States; two of these were in metal mines, one in an underground limestone mine, and one in a clay mine.

In 1940 Diesel locomotives were used underground during the driving and lining of the Delaware River Aqueduct in New York, and much information was obtained by the Bureau of Mines and the Division of Industrial Hygiene, New York Department of Labor, in connection with this enterprise; some interesting publications were issued concerning the locomotives used in driving and lining the Delaware Aqueduct tunnels.[20/] [21/]

Diesel-powered trucks have been used more or less successfully in the underground limestone mines or quarries of the Central States for approximately 10 years, but Diesel mine locomotives have not been used in that region so far as known.

Delaware River Aqueduct

The Delaware River Aqueduct, with a total length of about 85 miles of tunnels, included a section of tunnel 15 miles long that was driven from shafts spaced about 5 miles apart. The tunnels were circular in cross section, 17 to 19 feet in diameter, and the shafts were 14 feet in diameter; the tunnels were lined with concrete. The maximum strata thickness over the tunnels was 2,400 feet.

20/ Harris, William B., Greenburg, Leonard, and Werner, Gustav, Diesel Engines in Tunneling Operations: Trans., Am. Inst. Min. and Met. Eng., vol. 153, 1943.

21/ Stiefel, Fred W., Operation of Diesel Locomotives Underground: Trans., Am. Inst. Min. and Met. Eng., vol. 153, 1943.

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Five Diesel engines were used in the construction of the tunnels; the locomotives weighed 28,000 pounds each and were powered with Diesel engines capable of developing 160 b.h.p. at 1,600 to 1,750 r.p.m. The gage was 36 inches, drivers 28 inches, length over all, 15 feet 9-1/2 inches, and wheel base 4 feet 9-1/2 inches. The locomotive height was 6 feet 2 inches over all.

The engines were 4-cycle, and they had 6 cylinders with a bore of 5 inches and a 6-inch stroke. The engines were designed to be flameproof, as methane was found in the rock formation penetrated by the tunnel. The flame arresters were of the labyrinth type patterned after the arresters used successfully in Europe; they were placed on both the air intake and the exhaust.

The exhaust scrubber or conditioner is described[20] as follows:

> The exhaust gas leaving the engine passed through a water-jacketed manifold to an exhaust cooling box. A water spray was tapped into the box and supplied by means of a pump. The water from the spray was made to travel downward through the pipe in contact with the exhaust gas leaving the exhaust cooling box. The exhaust gas was discharged into the water contained in the cooling box through the perforated pipe. The gas then passed to the top of the box, where a perforated plate and a baffle plate were interposed to stop the spray. The gas was forced into a second cooling box designed to separate the water spray from the exhaust gas by means of another series of baffle plates. After leaving the second cooling box, the gases passed into a labyrinth of berles saddles. This tended to remove the soot and oil present in the exhaust gas. The discharge from the second cooling box was relatively free of noxious contaminants and was delivered to the fan behind the radiator, where it was diluted before it passed into the general air.

It was found desirable to have approximately 10,000 cubic feet of air per minute for each Diesel locomotive in order to avoid objectionable gas concentrations. These ventilation requirements in connection with operation of the Diesel locomotives were found to be sufficient to dilute and carry away the methane liberated in the tunnel as well as the exhaust gases from the locomotive. In one shaft, in both headings, an explosive concentration of methane of considerable volume could develop in about 2 hours without forced ventilation.

The concrete placing equipment used in tunnel lining had a capacity of 2,000 cubic yards, or about 4,000 tons, in 24 hours. The maximum haulage distance was 5 miles in some instances, with an adverse grade for the cars loaded with concrete. During this period, each train hauled 20 cubic yards of concrete, or a total of 40 tons. The total distance covered in 1 month was 11,017 miles, and the cost for the month was $0.0222 per ton-mile, covering all expenses. The actual cost of operating the Diesel locomotives for the month was:

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Labor	$7,609.00
Insurance at 15 percent	1,141.35
Fuel and lubrication	429.00
Repairs	600.00
	$9,779.35

Most of the technical information regarding the use of Diesel locomotives underground, insofar as American mines are concerned, was gained in connection with the Delaware Aqueduct project. Extensive tests were made on the exhaust gases from the engine both at the manufacturing plant and during actual operations underground. The results of the tests made at the factory are shown in table 4.

TABLE 4. - Results of tests on Diesel locomotives at the factory

Condition of test	Engine speed, r.p.m.	Carbon monoxide concentration in exhaust gas, percent*/
Idling	530	0.00
Intermediate	700	.01
High	909	.01
High	1,700	.01
High	1,600	.01

*/ These samples were analyzed by the iodine pentoxide method.

During the tunneling operations, tests were conducted on all of the Diesel locomotives under widely varying conditions of tunnel ventilation, but in general the tests show less than the accepted standard for safe concentration of carbon monoxide. The U. S. Public Health Service, American Standards Association, Bureau of Mines, and the Health Departments of many States regard 0.01 percent carbon monoxide as the maximum safe concentration for a working environment.

TABLE 5. - Results of tests on Diesel locomotives in tunnels

Rated horsepower, 1,600 r.p.m.	160
Number of cylinders	6
Capacity (tons)	14
Air:fuel ratio	20:1

Tunnel	A	A	C	B	B	C
Locomotive number	1	2	3	3	4, 5	6
Engine load	Idle	Idle	Idle	Load	Load	Load
Carbon monoxide concentration, percent:						
Manifold			0.15	0.10	0.10	0.15
Exhaust			0.35	0.03	0.03	0.03
Tunnel air:						
Maximum	0.0055	0.0025	0.0020	0.0025	*/0.0040	0.009
Minimum	0.0045	0.0000	0.0001	0.0010	0.0006	0.0001

*/ See footnote on page 31.

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TABLE 5. - Results of tests on Diesel locomotives in tunnels (cont'd.)

Tunnel	A	A	C	B	B	C
Locomotive number.....	1	2	3	3	4, 5	6
Engine load	Idle	Idle	Idle	Load	Load	Load
Rate of air flow, cubic feet per minute	3,600	12,000	25,000	25,000	45,000	18,500
Air movement, ft. per min.	15	50	85	85	200	70
Reaction of men	Poor	Fair	Good	Good	Good	Good

*/ This sample was taken in air downstream of both engines with one one engine idling, only 15 feet away from sampler, and is not representative.

Some of the requirements of design and maintenance of the Diesel locomotives used in the construction of the Delaware River Aqueduct tunnels are quoted below:

1. The engine fuel shall be equivalent in quality to that specified by the engine manufacturer and shall have a sulfur content not exceeding 0.5 percent. It shall be kept in clean condition and shall be free from all foreign contaminants before being used in the engine.

2. No fuel shall at any time be stored underground except that carried in the fuel tanks of the engine.

3. The fuel injection system shall be designed and constructed so that the ratio of air to fuel cannot be reduced below 20 to 1, and the fuel pump adjustment shall be sealed.

4. The engine shall be equipped with flame arresters on the intake and exhaust systems of such design that the surface temperature of the exhaust manifold shall not exceed 400°F., and the exhaust gas temperature at the point of discharge shall not exceed 160°F.

5. The engine exhaust gases shall be discharged into the atmosphere at a point remote from the engine operator.

6. The exhaust gases shall be cooled either by washing and/or spraying with water, so that no incandescent particles shall be discharged into the surrounding atmosphere.

7. Spent gases from the Diesel engine shall be diluted with at least 10 times their volume of air before being released into the underground atmosphere.

8. The level of water in the storage tank shall control a valve interlocked to the fuel line which will stop the flow of fuel oil before the water supply becomes exhausted.

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9. The carbon monoxide content of the exhaust gases leaving the engine manifold and before dilution shall not exceed 0.1 percent.

10. The carbon monoxide concentration at any point in the general tunnel air shall not exceed 0.002 percent.

11. The concentration of oxides of nitrogen at any point in the general tunnel air shall not exceed 40 parts per million.*/

12. The concentration of sulfur dioxide, aldehydes, visible smoke, or other irritants in exhaust gases shall not create toxic or irritating atmospheric conditions or reduce visibility in the tunnel with the end of the vent pipe not more than 150 feet from the face nor less than 25 feet beyond the car changer shall be maintained. The main vent pipe opening shall be at the crown of the bore.

13. Before operating a Diesel engine underground, primary exhaust ventilation at the rate of 10,000 cubic feet per minute or more per engine and a minimum air velocity of 30 linear feet per minute in the tunnel.

14. Auxiliary ventilation shall be by blowing at a rate of 3,000 cubic feet per minute or more, with the intake to this system not less than 250 feet outby the car changer and the discharge not more than 65 feet from the face. The minimum air velocity between the face and the exhaust main shall not be less than 10 linear feet per minute. The location of the auxiliary vent pipe shall be at the spring line. The auxiliary vent pipe shall be metal from the air intake to the car changer; flexible pressure tubing may be used between the car changer and the face. The intake to the auxiliary system must be so located that air entering it will not be contaminated by exhaust gases from the Diesel locomotive when operating between the auxiliary intake and the face of the tunnel.

15. Whenever a Diesel engine is used in underground-tunnel operations, all headings shall be separately ventilated by primary exhaust ventilation. When any portion of the primary exhaust ventilation is not functioning, no Diesel motor shall be running.

Diesel Locomotive in Underground Service at a Lead-Zinc Mine

A Diesel mine locomotive has been in service as a main-line haulage unit at a western lead-zinc mine for more than a year, and service is reported to be satisfactory. An old lead-zinc mine is being reopened by a

*Maximum concentration of oxides of nitrogen is 25 parts per million in most States.

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Figure 5. - Diesel mine locomotive in use at a western lead-zinc mine.

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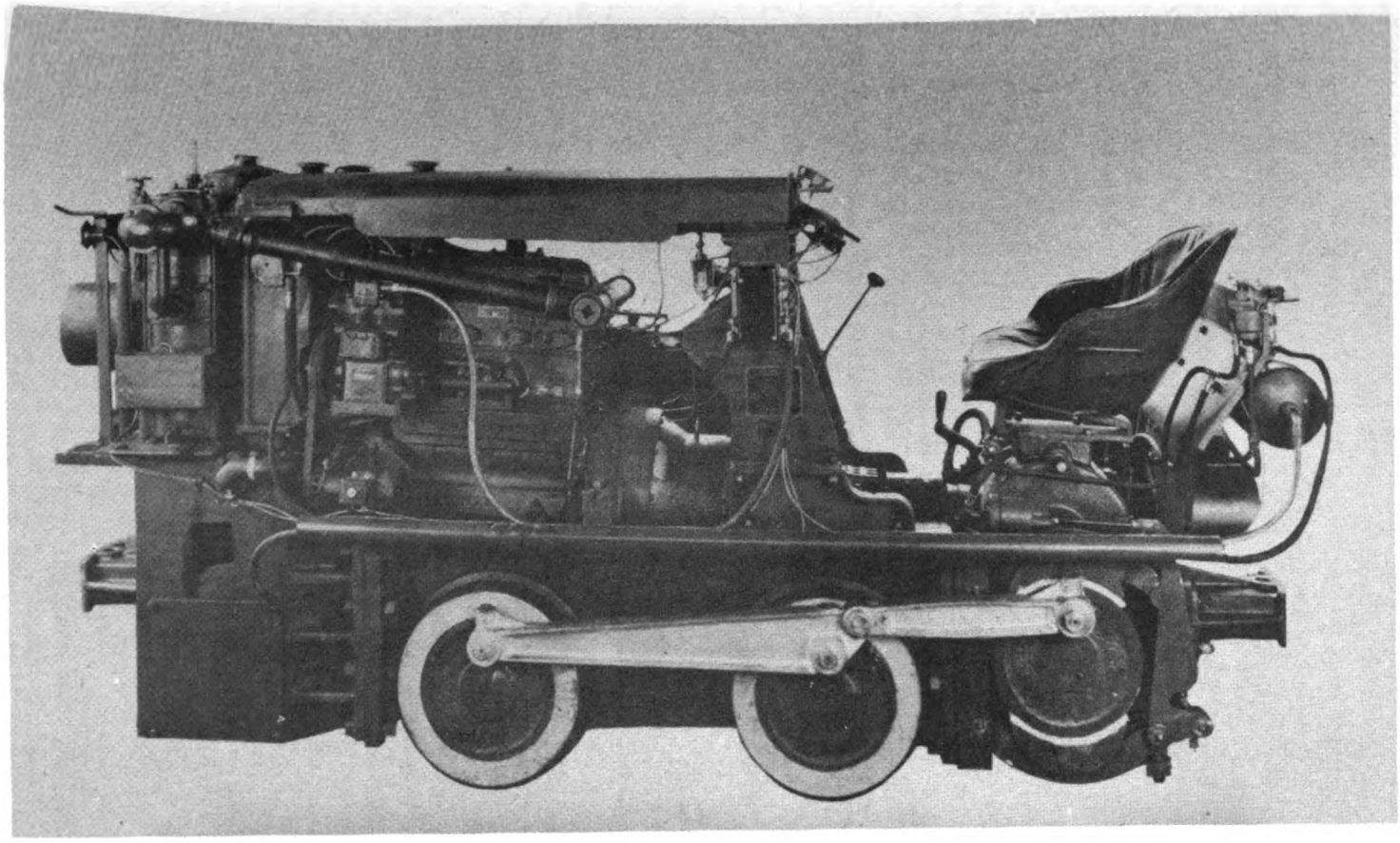

Figure 6. - Diesel mine locomotive of American manufacture.

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crosscut tunnel, which intersected the vein of ore about 1,100 feet below the lowest workings of the old mine. The altitude of the portal of the tunnel is 10,600 feet. The first 4,500 feet of tunnel was driven many years ago and is only 6 feet by 7 feet in cross section, with many places less than 6 feet high. The remainder of the tunnel, about 8,500 feet, is 8-1/2 by 8 feet in cross section. The tunnel grade ranges from 0.50 to almost 2.0 percent in favor of the load; the steeper grades are in the older portion of the tunnel.

The mine management decided that the smaller section of the tunnel did not allow sufficient height for electric trolley locomotives to operate safely and installed a Diesel mine locomotive as a main-line haulage unit after having obtained approval from the Commissioner of Mines of that State; permission was granted to use the Diesel locomotive for a distance of 8,500 feet in from the portal of the tunnel. (Fig. 5.)

The Diesel mine locomotive as originally installed weighed 5 tons, but it has since been increased to 6 tons in order to give the locomotive more traction. The Diesel engine develops 65 b.h.p. at sea level but, because of the high altitude, develops 55 b.h.p. at the tunnel altitude. There is a loss of 1-1/2 percent of the engine power for each 1,000 feet increase in altitude. Some pertinent data relative to this locomotive are tabulated below (fig. 6):

Height, over all	4 feet, 6 inches
Length, over all	12 feet
Width, over all	3 feet, 3 inches
Track gage	24 inches
Brakes	Westinghouse air brakes
Air brake-cylinder pressure	125 pounds
Couplers	Front and rear of locomotive-midget type automatic locomotive couplers
Drive	Side rods
Wheels	Manganese steel alloy tires shrunk on cast iron centers
Speeds	5 in either direction
Locomotive frame	Cast steel
Headlights	Front and rear
Fuel consumption, 8 hours	6 gallons, average

The rails in most of the tunnel track weigh 45 pounds per linear yard; lighter rails are being replaced with rail of this weight.

The mine cars are 60-cubic foot Granby-type and have a capacity of 3 tons of ore; the empty car weighs 2 tons. The locomotive normally pushes 15 empty cars into the mine and returns with 15 loaded cars. A maximum of 26 empty cars has been pushed into the mine on a single trip. The haul

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from the chutes to the mill track is approximately 2 miles. The locomotive has brought out 120 loaded cars in an 8-hour shift under actual working conditions. The estimated capacity of the mine locomotive in terms of ton-miles is said to be 500 ton-miles of loaded cars and 200 ton-miles of empty cars, or a total of 700 ton-miles in 8 hours. (Fig. 7.)

The engine is reported to start easily; a 12-volt, 140-ampere battery starter and generator are used.

The locomotive is equipped with Westinghouse air brakes and two hand-operated emergency brakes. The air brakes are on the driving disks; one emergency brake is on the four brake shoes that contact each wheel, and the other brake is on the transmission.22/ Owing to the heavy loads and steep grades coming out of the tunnel, more than ordinary braking power is desirable; a special brake car weighing 3 tons is fitted with air brakes on all four wheels and is coupled to the engine at all times. The brake car is fitted with two seats and is used to transport samplers and supervisory personnel in and out of the mine during the shift.

An unusual type of exhaust-gas conditioner or scrubber was developed for this mine locomotive.23/ The conditioner tank, capacity 4 cubic feet of water, has a circular core placed horizontally in the tank, around which the water circulates. The exhaust gas enters the manifold of the conditioner and is conducted below the water level through diffusion tubes, which extend well below the water level. As the exhaust gas is discharged into the water, it causes the water to circulate around the core; the water circulating in an upward direction in the tank has a tendency to break the large bubbles of exhaust gas into relatively small bubbles. It is important that the diffusion of the bubbles is not so great as to prevent separation of the water from the exhaust gas when it arrives in the upper separation chamber on top of the conditioner tank; this is controlled by the velocity of the water and the diameter of the diffusion tubes. A "semi-spitzkatzen" used in conjunction with a series of baffles separates out most of the water in the separation chamber. A secondary chamber placed above the separation chamber contains a cyclone separator, which removes most of the remaining water from the exhaust gas and allows the gas to escape to the atmosphere and the water to return to the circulating stream. Means are provided to clean the diffusion tubes of any wax, oil, or carbon in the exhaust gas that accumulates on their inner surface owing to lowering of the temperature of the gas. Cleaning the tubes is a simple operation and must be done about once a week. The conditioner is more efficient when the engine is working under heavy load, as the temperature of the water increases. The exhaust gas from the engine escapes as a vapor, which condenses and is virtually steam. The manufacturer states that condensation of the vapor precipitates the solid particles that would remain in a colloidal state in the air, and thus smoke is eliminated by the conditioner.

22/ Ruth, Joseph P., Ruth Diesel Locomotive Speeds Ore Haulage, 11,000 Feet Altitude: The Mines Magazine, vol. XXXV, No. 7, 1945.

23/ Plumb, C. W., Diesel Locomotive for Underground Haulage: Am. Min. Cong. Jour., vol. 32, No. 10, 1946, p. 77.

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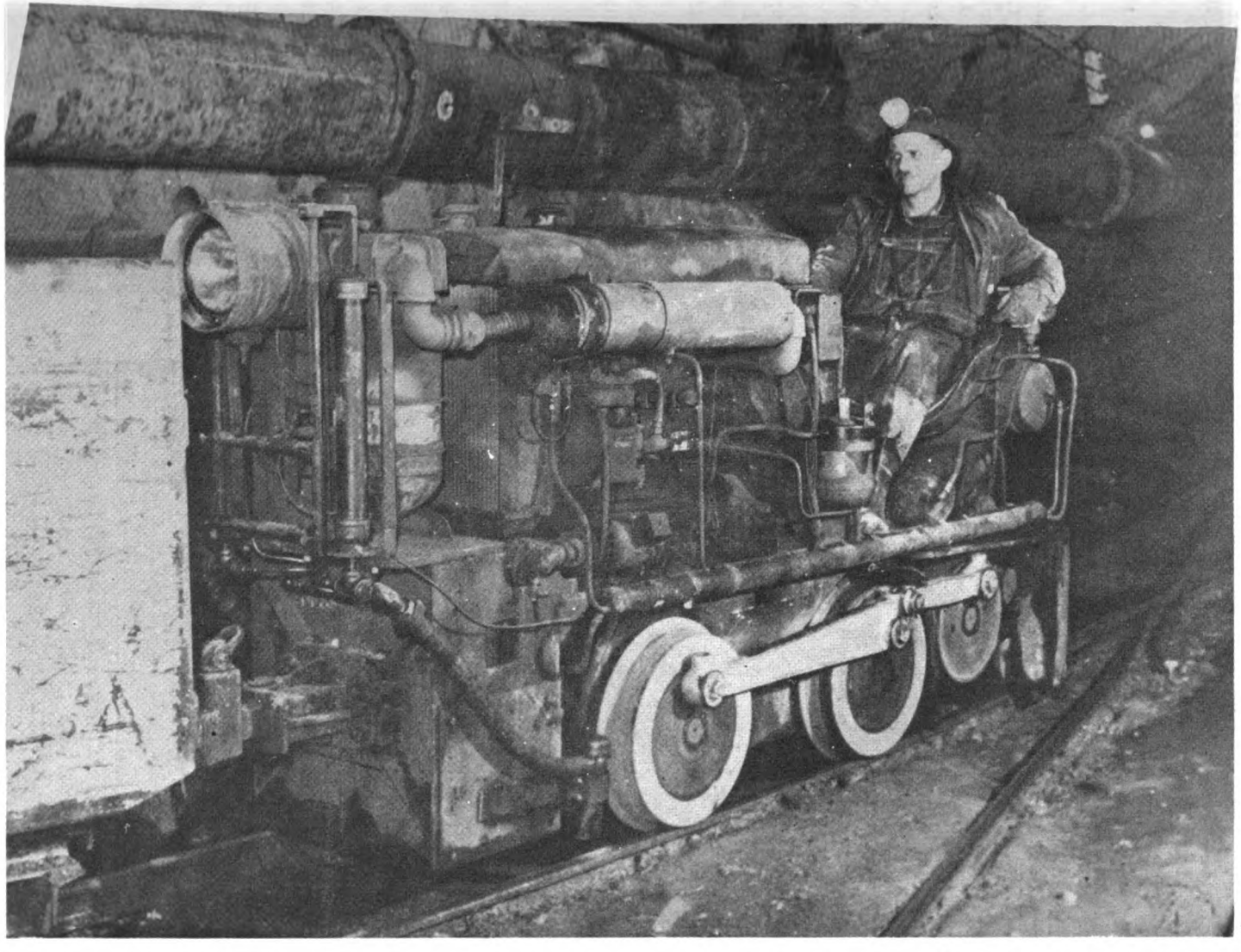

Figure 7. - American manufactured Diesel mine locomotive in a western lead-zinc mine.

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At present, the tunnel workings are ventilated by means of a suction fan at the surface and an 18-inch steel pipe; a booster fan is situated 8,500 feet from the portal, and it is stated that 5,000 cubic feet of air per minute is delivered to the headings. When a raise now being driven is completed and the lower workings are connected with the old mine above, ventilation of this mine is expected to be improved, and it is hoped that it will be possible to operate the Diesel mine locomotive in all parts of the tunnel.

Samples of the general mine air taken at the end of the Diesel mine locomotive run, 8,500 feet from the portal of the tunnel, were analyzed as follows:

	Sample number and date taken		
	1 7-12-46 Percent	2 7-12-46 Percent	3 9-5-46 Percent
Oxygen	20.25	20.12	19.98
Nitrogen	79.34	79.41	79.56
Carbon dioxide	0.41	0.47	0.46
Carbon monoxide	0.00	0.00	Less than 0.005
	100.00	100.00	100.00
Oxides of nitrogen parts per million	17	13	28

A sample of the exhaust gas was taken from the engine exhaust pipe while the engine was idling; the analysis of this sample follows:

	Percent
Oxygen	19.42
Nitrogen	79.41
Carbon dioxide	1.15
Carbon monoxide	0.02
Methane	0.00
	100.00
Oxides of nitrogen, parts per million	*
Temperature, °F.:	
Dry bulb	44
Wet bulb	43
Relative humidity, percent	96
Barometric pressure, inches	20.15

*Extraneous matter in the sample tube prevented analysis.

Remarks

The successful use of the Diesel locomotive underground at this mine is of particular interest because of the high altitude at which the mine is situated - 10,600 feet above sea level; most European mines using Diesel locomotives have an altitude of less than 1,500 feet.

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The use of the weighted car fitted with air brakes to give additional braking power and thus better control the trips of loaded cars on the steep grades coming out of the tunnel is unique in American practice, although air brakes on man trip cars are not uncommon in Europe.

The air analyses indicate the need of better ventilation of the tunnel; this should be attained by completion of the raise connecting the tunnel with the lower workings of the old mine above. Both the carbon dioxide and the oxides of nitrogen in the general mine air at the end of the Diesel run approach the suggested maximum limits for Diesel-engine operation underground; however, no untoward occurrences have been caused by the installation as of February 1947.

Diesel Locomotive in an Underground Limestone Mine

A Diesel locomotive is used for haulage unit in an underground limestone mine in one of the Western States; this is believed to be the first small Diesel mine locomotive used underground in the United States. The locomotive has been in constant service for nearly 2 years. Altitude at the portal of the tunnel is 6,550 feet.

Two steeply dipping limestone beds, 21 and 22 feet thick, respectively, have been opened by a crosscut tunnel 8 by 14 feet in cross section. Drifts are driven right and left at the intersection of each bed of limestone, and the shrinkage-stope system of mining is used to extract the limestone. Only enough broken rock is drawn from the stopes through chutes on the haulage level to provide head room for the miners. The crosscut tunnel intersects the farthest limestone bed approximately 3,500 feet from the portal. An average of 6,500 tons of rock a month is hauled from the tunnel.

The broken limestone is drawn from chutes into 5-cubic yard side-dump cars and hauled to the crushing plant on the surface by a 5-ton Diesel mine locomotive. The track gage is 24 inches, and the rails weigh 40 pounds per linear yard. Double tracks extend the full length of the haulage tunnel.

Mechanical ventilation is not provided, but considerable circulation of the air is obtained through the empty stopes driven to the surface. Construction of a new ventilating system is in progress; a 50,000 c.f.m. fan, operating blowing, will be placed in the haulage level. The air will be drawn into the crosscut tunnel by the fan and forced into the stopes, and will escape to the surface through the numerous mine openings. Mine doors will be used to direct the flow of air into the stopes.

The exhaust-gas conditioner on the Diesel engine was disconnected, and the exhaust gas from the engine was discharged into the air without washing. The odor of aldehydes was present in the mine air but was not strong enough to be obnoxious.

A supersensitive carbon monoxide indicator was operated in various places in the haulage tunnel, particularly in the vicinity of the loading chutes and near the face of the tunnel. The highest concentration of carbon monoxide registered on the indicator was 0.0025 percent.

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Samples of mine air analyzed for oxides of nitrogen gave the following results:

	Oxides of nitrogen, parts per million
General mine air near locomotive while engine was idling at the end of the Diesel run	14
General mine air near a loading chute about 100 feet from Diesel engine. Engine was idling.	0
General mine air at end of Diesel run. Engine idling about 50 feet away from sampler.	4
General mine air at end of Diesel run, engine idling.	15

No trouble as to respiratory conditions or as to fires or explosions has been experienced with the Diesel mine locomotive in 2 years of operation; in addition, the installation has been definitely satisfactory from the standpoint of cost and efficiency.

Remarks

The use of Diesel locomotives or any type of internal combustion engine underground without mechanical ventilation is regarded by the Bureau of Mines as hazardous. Naturally induced ventilating air currents may change their direction because of variations of temperature and barometric pressure, or the air may remain stationary relatively long under some conditions. The mechanical ventilating system now under construction should provide abundant ventilating air to dilute and carry away the exhaust gas from the Diesel engine as well as ventilation of the mine workings.

An efficient gas conditioner or scrubber removes most of the aldehydes from the exhaust gas of a Diesel engine, with the result that employee opposition to its use because of the odor is virtually removed. The conditioner also absorbs some of the oxides of nitrogen, and it should be utilized and kept in good working condition at all times.

Diesel Locomotive in an Underground Clay Mine

An underground clay mine in an Eastern State uses a 10-ton Diesel locomotive as a main-line haulage unit, transporting about 135 tons of clay 10,500 feet underground and 2,300 feet on the surface to the preparation plant. The locomotive has been in service since October 1941.

The mine is opened by a drift, which serves as a haulageway, and by two vertical shafts used for ventilation. The clay formation is nearly horizontal, and a two-entry room-and-pillar method of mining is used. The entries are driven 10 feet wide and 6 feet high, and the rooms are advanced 20 feet

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wide and 5 to 6 feet high for a distance of 300 feet; pillars are recovered on retreat. The mine operates one shift a day.

The total length of haul underground is 10,500 feet, of which 8,900 feet is graded in favor of the load and 1,600 feet is an adverse grade; the 2,300-foot haul on the surface is an adverse grade. The grades favoring the load average 4.04 percent for 8,800 feet and the adverse grade averages 1.85 percent.

Circulation of air in the mine is induced by a 4-foot, 10-blade, disk fan operating exhausting; the water-gage pressure is 0.60 inch, and about 12,000 cubic feet of air is circulated through the mine per minute. The main haulageway is ventilated by return air, and the air containing the exhaust gases from the Diesel engine does not pass through the working places. The coursing of the air is controlled by wooden doors and brick stoppings.

The Diesel locomotive usually makes three round trips underground each day; a round trip requires 1 to 1-1/2 hours, but the actual running time averages 22-1/2 minutes for a trip of loaded cars from the underground switch yard to the mine scales at the end of the run and 23-1/2 minutes to return with a trip of empty cars. A trip is composed of 21 cars having a total weight when empty of 13 tons. The normal weight of clay handled per trip is 45 tons, making a gross weight moved of 68 tons, including the weight of the locomotive. The Diesel engine is not permitted to idle underground.

The Diesel locomotive was designed specifically for conditions in this mine. Some of the general specifications follow:

Diesel locomotive specifications

Weight of locomotive	10 tons
Height over all	4 feet, 8 inches
Length over all	13 feet, 4 inches
Width over all	5 feet
Track gage	36 inches
Diesel engine:	
Cycles	4
Cylinders	6
Bore of cylinder	4-1/4 inches
Piston stroke	5 inches
Piston displacement	425.31 cubic inches
Horsepower, maximum:	
At 2,000 r.p.m.	165
At 1,200 r.p.m.	125
Compression ratio	16:1
Engine exhaust stacks, 3 inches diameter	2
Transmission	4 speeds, separate reverse gear
Chain drive from rear axle to front wheels.	

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Diesel locomotive specifications (cont'd.)

Brakes	Vacuum and hand-operated
Throttle	Hand- and foot-operated
Clutch	Hand-operated
Fuel-tank capacity	14 gallons
Sanders	Separate for front and rear wheels.

Mine air samples were taken before and after changing the fuel injectors on the Diesel engine. The analyses follow:

Before changing injector

	Return air on main haulageway, Locomotive hauling 21 empty cars	Face room A	Face room B
Oxygen	20.71	20.43	20.44
Nitrogen	79.16	79.21	79.37
Carbon dioxide	0.13	0.35	0.19
Carbon monoxide	Less than .005	Less than .01	0.00
Methane	0.00	0.00	0.00
	100.00	100.00	100.00
Oxides of nitrogen, parts per million	0	-	-

After changing injector

	I	II		
Oxygen	20.75	20.77	-	-
Nitrogen	79.16	79.13	-	-
Carbon dioxide	0.09	0.10	-	-
Carbon monoxide	0.00	0.00	-	-
Methane	0.00	0.00	-	-
	100.00	100.00		
Oxides of nitrogen, parts per million	0	0		

Typical analyses of the exhaust from the Diesel engine taken at different times and under varying conditions are shown below:

	Engine idling	Locomotive hauling loaded trip upgrade	Locomotive hauling 21 empty cars	Locomotive hauling 21 loaded cars
Oxygen	20.04	15.48	13.69	13.04
Nitrogen	79.27	80.52	81.03	80.96
Carbon dioxide	0.64	3.87	5.24	5.88
Carbon monoxide	0.05	0.11	0.04	0.09
Methane	0.00	0.02	0.00	0.03
	100.00	100.00	100.00	100.00
Oxides of nitrogen, parts per million	21	173	207	295

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The Diesel engine is overhauled once a year, and the fuel-injection system is serviced every 6 months. The intake-air cleaners and oil filters are cleaned once a week, and the compounded lubricating oil is changed every two weeks.

The engine is equipped with a manually operated, quick-acting valve in the air-intake system, so that in case of failure of the governor and fuel shut-off in the fuel-supply line, the engine can be stopped by cutting off the supply of air. Fuel consumption is between 6 and 8 gallons of fuel oil per day when production is approximately 135 tons.

Specifications of the fuel purchased for this Diesel locomotive are as follows:

Fuel-oil specifications

Gravity, A.P.I., 60°F.	40
Flashpoint, P.M.C.C., °F.	160
Viscosity, S.U. at 100°F., seconds	33
Sulfur, percent	0.11
Carbon residue, percent	0.01
Neutralization number	0.05
Water and sediment, percent	Nil
Diesel index	64
Distillation range, °F.:	
Initial boiling point	350
50 percent	458
90	590
End-point	650

The Diesel locomotive is not equipped with an exhaust-gas conditioner, or scrubber, but has a blower, which, according to the manufacturer, is about 1.4 times the piston displacement of the engine; the exhaust gases are diluted to the extent that the blower delivery exceeds the piston displacement.

The production of smoke and irritating and odorous materials by the Diesel engine is not considered objectionable under intermediate or heavy loads, but under light loads, particularly on a downgrade haul, considerable smoke, odor, and irritation are evident to the rider on the rear end of a loaded trip. This condition does not exist at the locomotive on either upgrade or downgrade haulage underground, probably because the speed of the engine (about 500 feet a minute) is faster than the movement of the ventilating air current, which is about 225 feet per minute.

Remarks

The ventilating currents are capable of diluting and carrying away the toxic gases from the exhaust of the Diesel engine, but under certain conditions the smoke, odors, and irritating material are noticeable. An efficient

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exhaust-gas conditioner or scrubber would remove at least some of these undesirable materials.

The haulageway at this mine is on return air, hence any odors, smoke, or irritants produced in the engine exhaust do not go into the working places, where they might have an adverse effect upon the employees working there. This illustrates the advantage of having haulageways in which Diesel locomotives are working on a separate split of air, so that the air will not go into the working places, or on return air, as at this mine.

Diesel Locomotive for Main-Line Haulage in a Western Coal Mine

At a bituminous coal mine in a western State a Diesel locomotive was installed as an underground main-line haulage unit. Permission to operate the locomotive in this manner was obtained from the chief coal mine inspector of the State on April 2, 1946, and it was placed in underground service on May 22, 1946.

The permit to operate the Diesel locomotive underground was granted under the following conditions:

1. The locomotive shall be operated on an intake air road used as a haulageway.
2. The locomotive shall only be operated for a distance of 1,200 feet inside the mine from the portal under ventilating conditions as stated in 1.
3. Mine inspectors of the United States Bureau of Mines may examine the arrangements at any time and make such tests as they deem necessary to check on the safety of the installation.
4. The use of the locomotive must be stopped immediately if any hazard to the workmen develops from its operation.

The mine is opened by three slopes driven from the outcrop, up the dip of the coal bed, which averages about 6 percent in favor of the load. Starting at about 500 feet from the portal, the development plan was changed, and four slopes were driven instead of the original three slopes. The two middle slopes are used as intake-air passageways, and the two outer slopes are for return air. The mine is rated as gassy by the Federal Bureau of Mines.

The coal bed ranges from 4 feet, 2 inches to 19 feet, 3 inches in thickness, but the bed is subject to severe "rolls," and in some places the coal has been entirely eroded. The coal is loaded with mechanical loaders and transported to a loading track by shuttle cars. The mine cars are hauled to and from the main-line assembly parting with 5-ton storage-battery locomotives.

The coal cars yield 2.65 tons, and the Diesel locomotive hauled eight cars on each trip. A round trip required an average of 12 minutes.

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The Diesel locomotive is powered with a 48-b.h.p. Diesel engine. The locomotive was first placed in service as a switch engine in the tipple yard on November 11, 1944, and was not overhauled before being placed in underground service. The engine was not equipped with flame arresters on the intake and exhaust, and the final exhaust did not pass through a scrubber or exhaust-gas conditioner. Figure 8 is a picture of this locomotive.

The locomotive has five speeds ahead, ranging from 1.5 m.p.h. in first gear to 15.3 m.p.h. in fifth gear. The locomotive pushed the empty cars upgrade into the mine and was attached on the front end of the trip as it left the mine. A locomotive engineer and a brakeman comprised the crew of this unit.

The haulageway is on intake air and measures 60 square feet in cross section near the portal. The ventilating air measured 37,000 cubic feet per minute at this point. The cross-sectional area of the haulageway near the end of the Diesel run measures 78 square feet and the ventilating air measured 20,000 cubic feet per minute.

Air samples taken in the main return airway by Bureau of Mines coal-mine inspectors prior to placing the Diesel locomotive in service were analyzed as follows:

	Percent
Oxygen	20.82
Carbon dioxide	0.05
Methane	0.12-0.22

Samples of the general mine air in which the Diesel locomotive was operating, taken near the end of the run, analyzed as follows:

	Percent
Oxygen	20.89
Nitrogen	79.02
Carbon dioxide	0.08
Carbon monoxide	Less than 0.01
	100.00
Oxides of nitrogen, parts per million	7
Temperature, °F.:	
Dry bulb	63
Wet bulb	58
Relative humidity, percent	76
Barometric pressure, inches	24

A supersensitive carbon monoxide indicator was operated continuously while the Diesel mine locomotive made several round trips from the underground assembly yard to the tipple; the greatest amount of carbon monoxide noted was 0.0035 percent, while the locomotive was passing the indicator. The indicator immediately returned to zero after the locomotive had passed.

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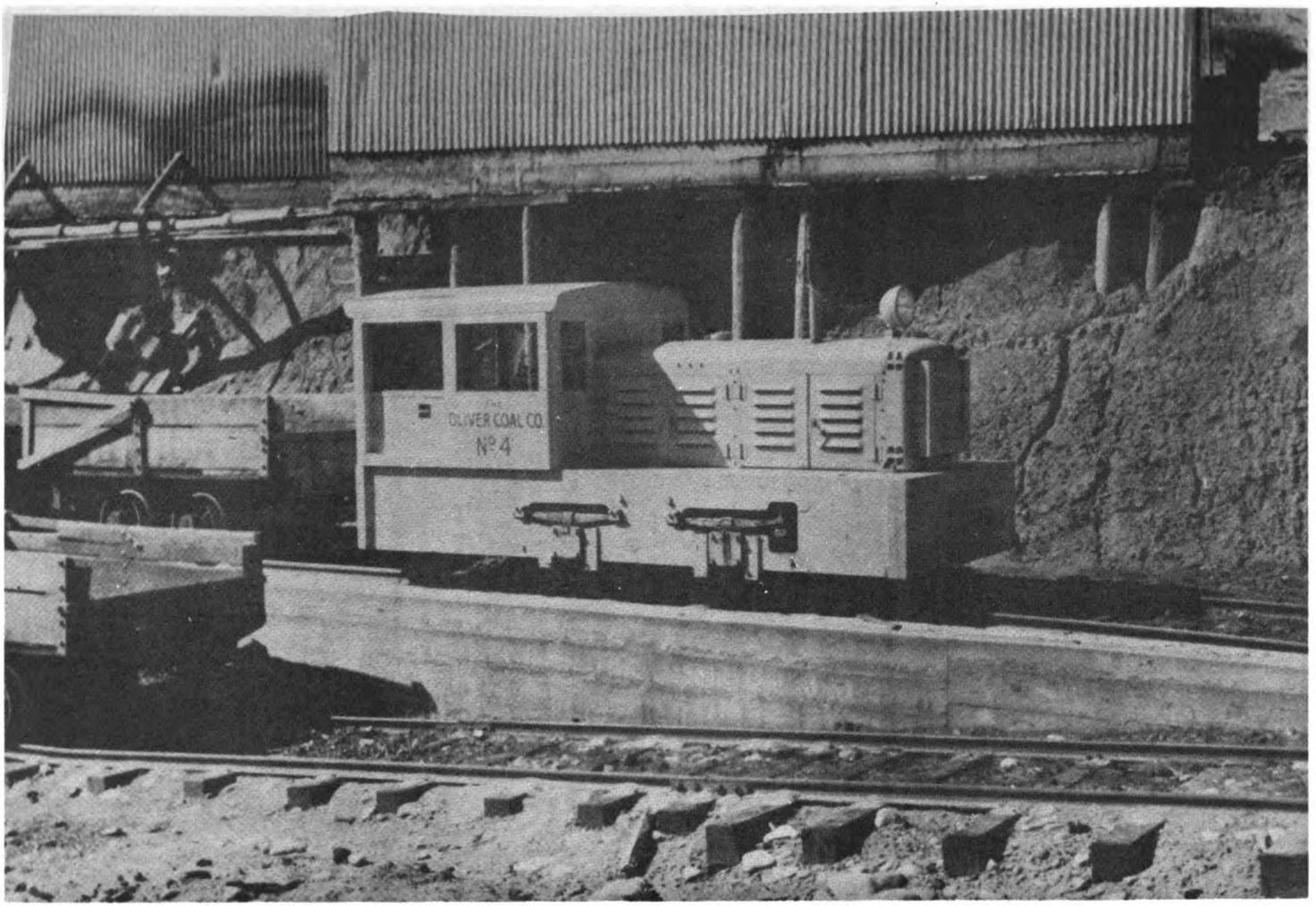

Figure 8. - Diesel locomotive that was used as an underground main line haulage unit at a western coal mine.

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The supersensitive carbon monoxide indicator detects accurately concentrations of carbon monoxide in the range of 0.1 to 0.001 percent and concentrations as low as 0.0025 percent can be estimated.

Samples were taken of the gas from the Diesel-engine exhaust pipe while the engine was idling after pushing eight empty mine cars up the approximately 6-percent grade from the portal. The analysis of the exhaust gas follows:

	Percent
Oxygen	18.44
Nitrogen	79.73
Carbon dioxide	1.76
Carbon monoxide	0.03
Methane	0.04
	100.00
Oxides of nitrogen, parts per million	39

The specifications of the fuel oil that was used in this locomotive follow:

	Summer	Winter
Flash	160-170	145-150
Viscosity-SU at 100°	35	33
Pour	0	-20
Cloud point	5	51
Cetane (calculated)	55	51
Color Saybolt	Below -16	Below -16
Sulfur, percent	0.08	0.08
Diesel index	61	62
Carbon residue, percent on 10 percent of residue	0.04	0.04
BS&W	Nil	Nil
BTU content	18,480	18,500
Gravity	39	40
Volatility:		
IBP	375-385	340-350
10 percent	445-455	405-415
90 percent	540-550	530-540
End point	580-600	575-600

The Diesel engine emitted black smoke while pushing the empty trip into the mine; this was probably due to the fact that the engine was not in good operating condition, as it was not overhauled before being placed in underground service. The odor of aldehydes was not strong enough to be obnoxious and was quickly dissipated by the ventilating air current.

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Remarks

This Diesel locomotive gave efficient service while it was operated, but it was removed from the mine after the Federal Coal Mine Safety Code went into effect because it was nonpermissible, hence its use was prohibited by the Code. The aldehydes in the exhaust gas of a Diesel engine can be almost completely absorbed by installing an efficient air conditioner or scrubber; water is one of the best absorbents of aldehydes. The water in the scrubber should be maintained at the correct level, and the water should be changed at frequent intervals.

Diesel engines used in underground work should be maintained in good mechanical condition at all times, otherwise the noxious gases in the engine exhaust increase rapidly, and much smoke may be emitted. Some companies keep a record of the hours a Diesel engine operates, and establish a time interval for complete overhaul of the engine.

USE OF DIESEL-POWERED EQUIPMENT OTHER THAN LOCOMOTIVES IN UNDERGROUND MINES IN THE UNITED STATES

Trucks powered with both gasoline and Diesel engines are used extensively as haulage units in underground limestone and sandstone mines in the Central States and in the Tri-State lead and zinc district. The mines are usually in flat or nearly flat formations, where it is possible to build roads without excessive grades. The mine workings vary greatly in height, but usually range from 12 to 50 feet high. The overlying rock is supported by pillars, and usually there are several openings to the surface, which provide fairly good natural ventilation. (Figs. 9, 10, 11, 12, 13.)[24] The cross-sectional area of most of these mine workings is so large that the exhaust gases from the internal-combustion engines are diluted, and the movement of air inside the mine is sufficient to carry the exhaust gas away from the engines. Mechanical methods of ventilation are used seldom in these noncoal mines with adit openings; a few are opened with shafts, and these are ventilated much as is a coal mine.

Diesel Trucks in an Underground Limestone Mine in Pennsylvania

An important underground limestone mine in Pennsylvania changed its haulage system from steam-powered locomotives to Diesel trucks on April 1, 1939. The mine delivers approximately 300 tons of limestone to the crushing plant daily.

The Industrial Board of the Commonwealth of Pennsylvania granted permission to the company to use Diesel-powered trucks underground under the following conditions:

1. That the truck motors be stopped when loading and operated only when the trucks are in motion.

24/ Illustrations were furnished by the courtesy of the Caterpillar Tractor Co.

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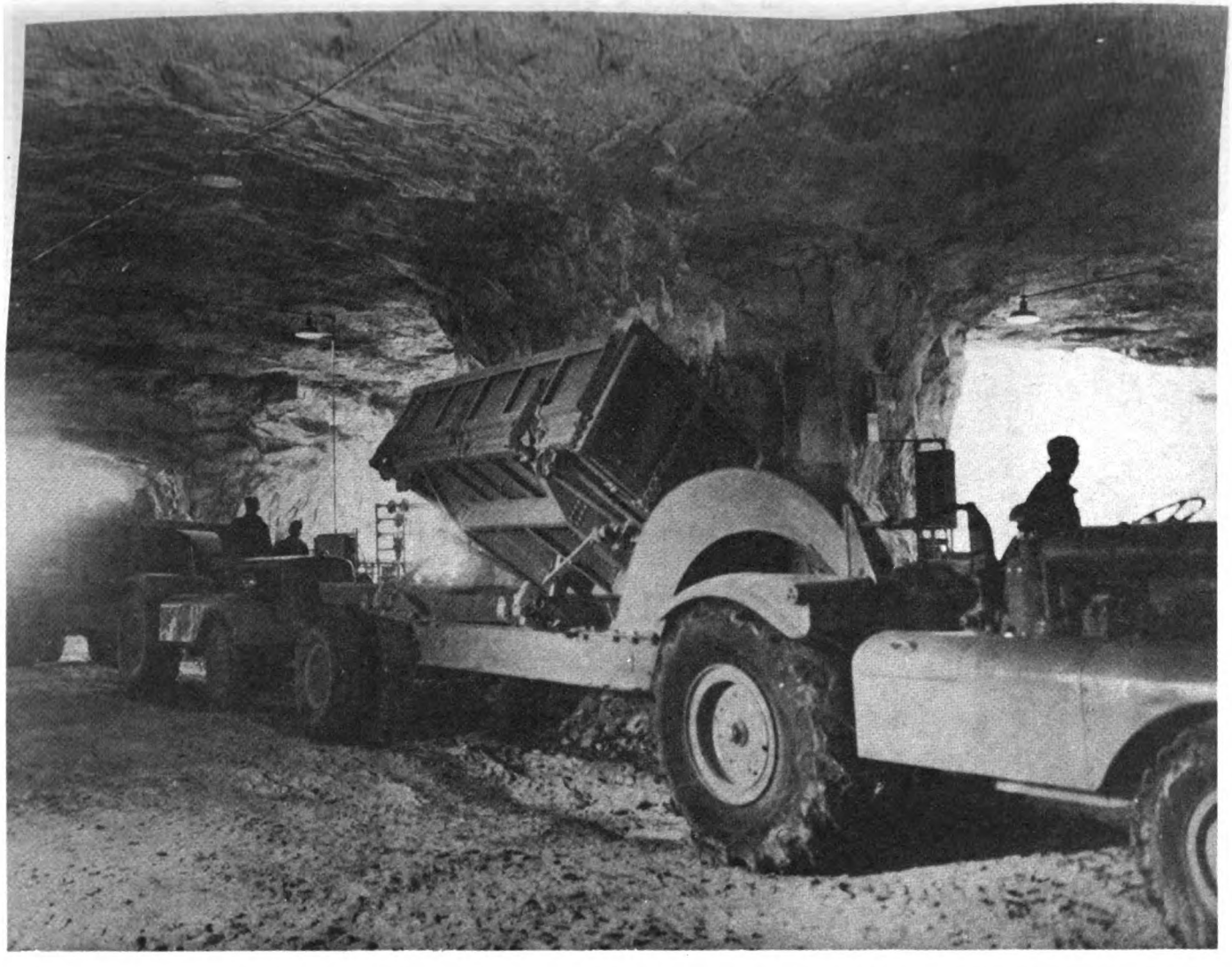

Figure 9. - Typical Diesel-powered truck-haulage units used at some of the underground limestone mines.

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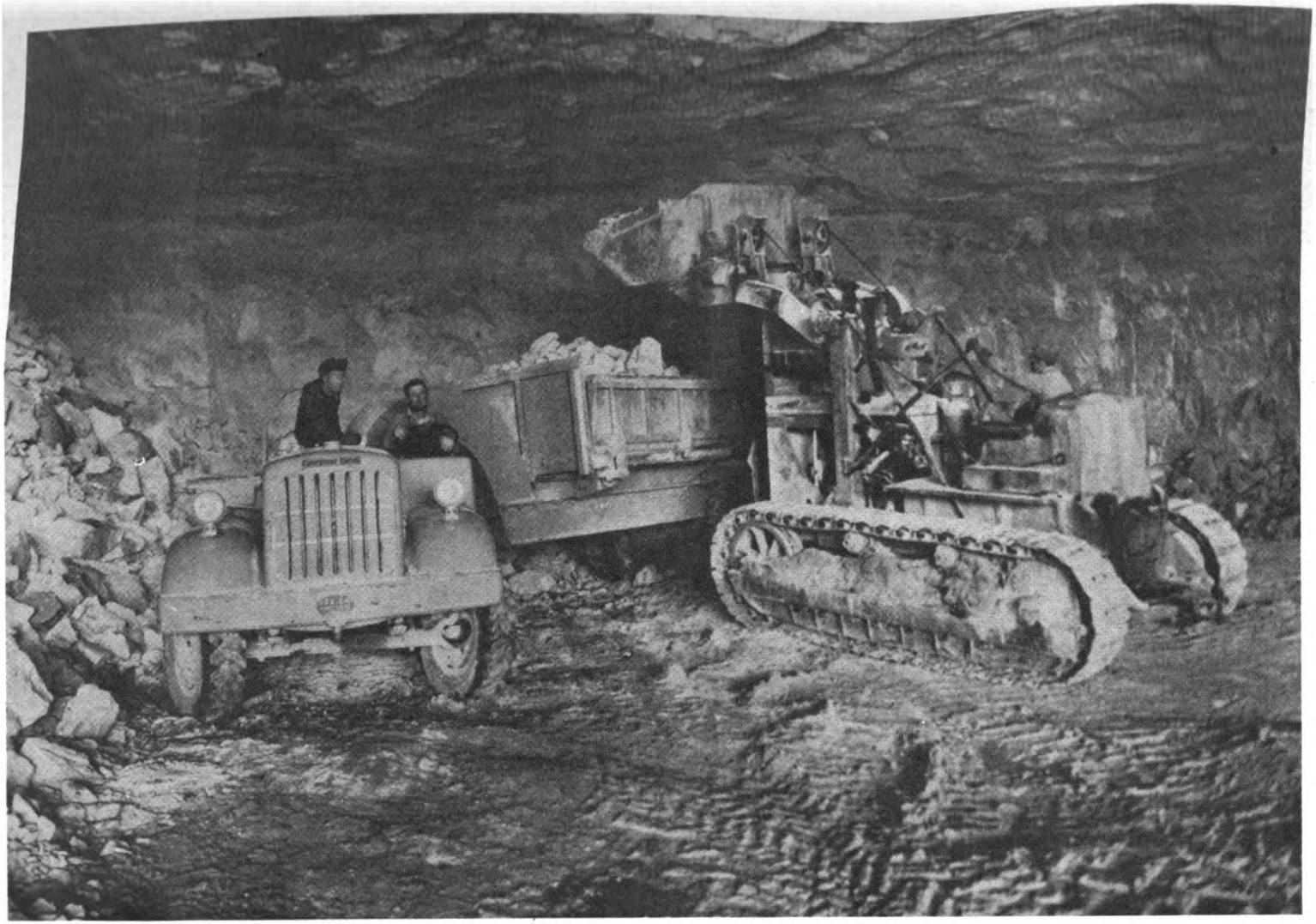

Figure 10. - Diesel-powered equipment used in some of the underground limestone mines in Missouri.

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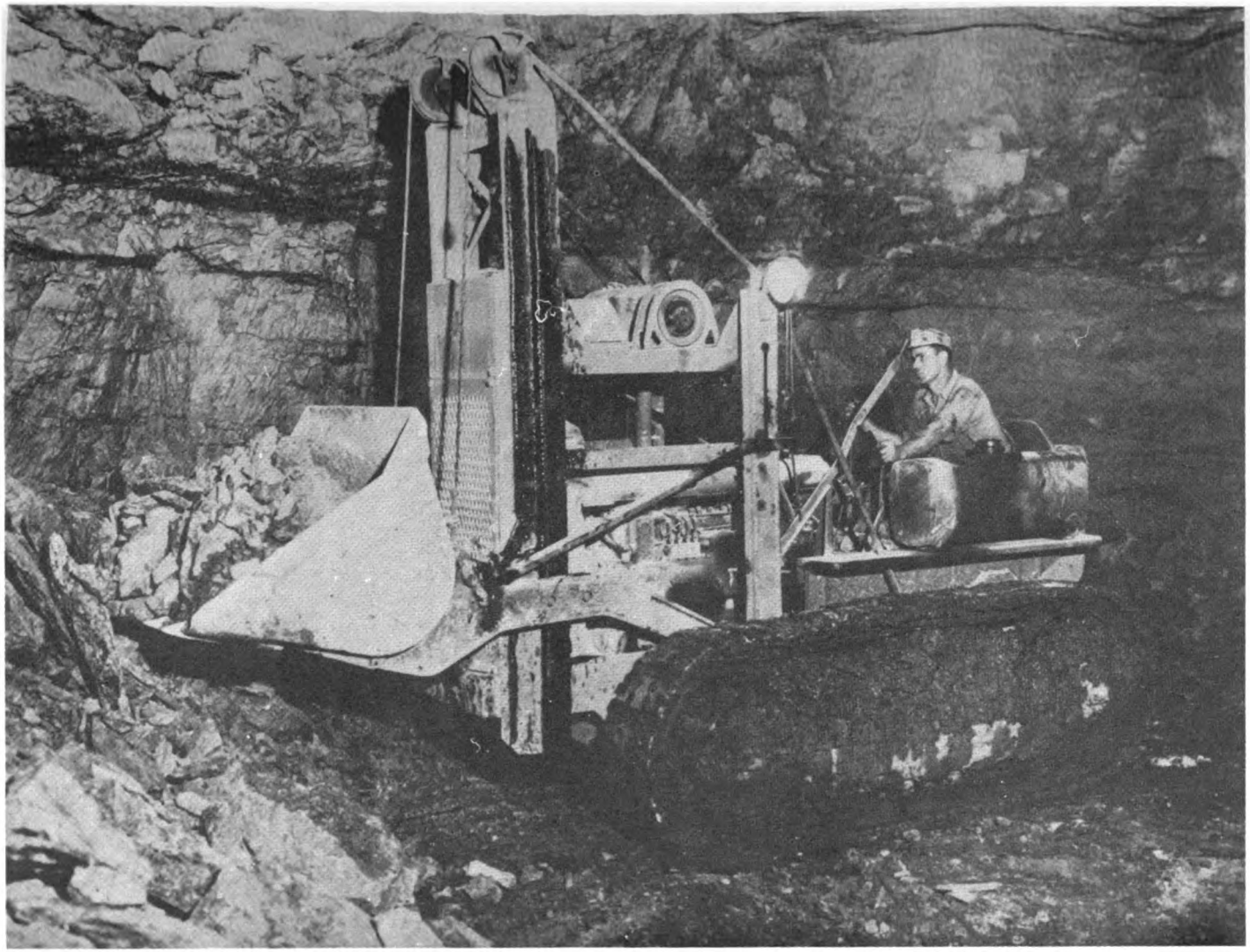

Figure 11. - Small Diesel-powered loading unit used in some limestone mines for loading trucks and for clean-up purposes.

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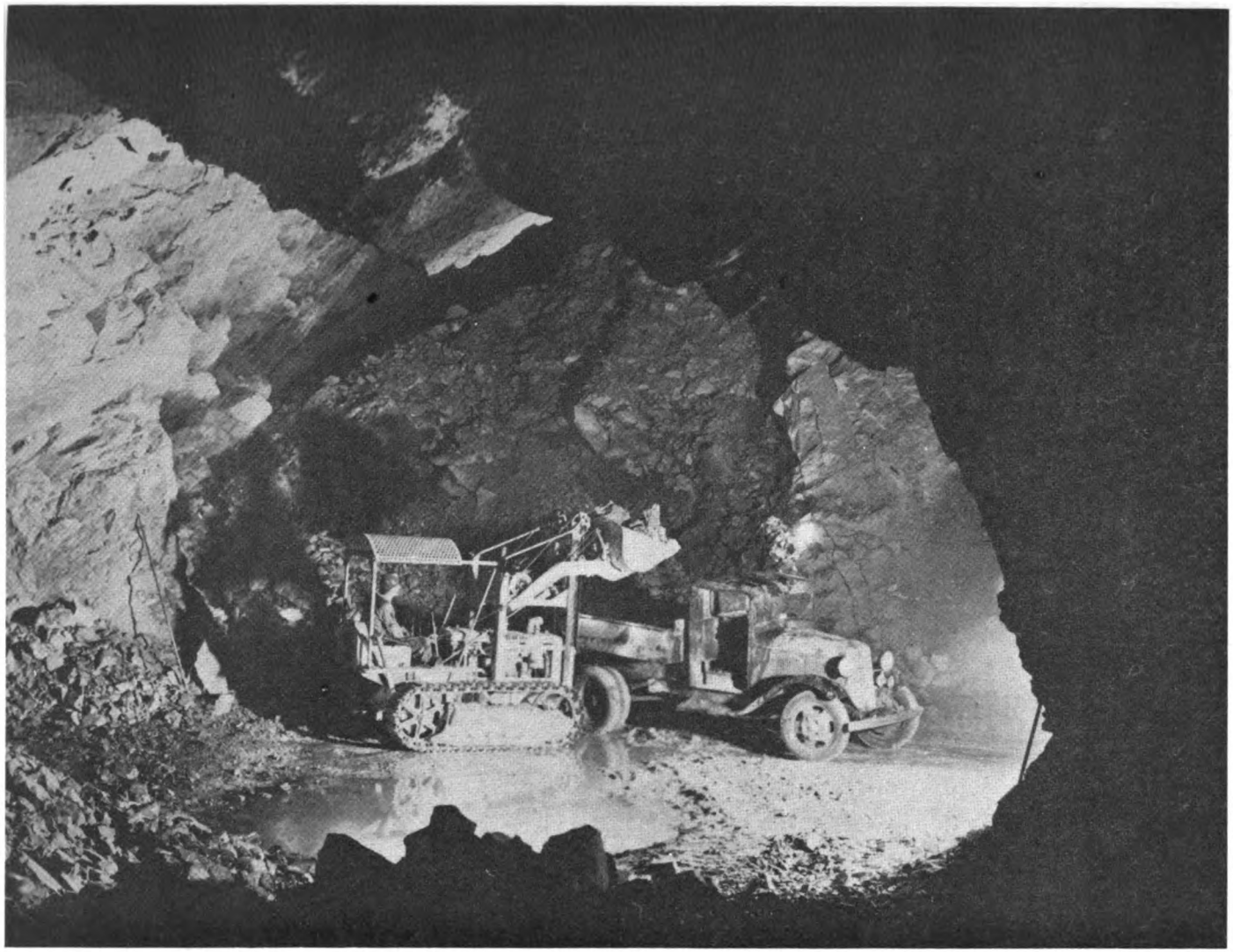

Figure 12. - Loading limestone with a Diesel-powered unit underground. The truck is not Diesel powered.

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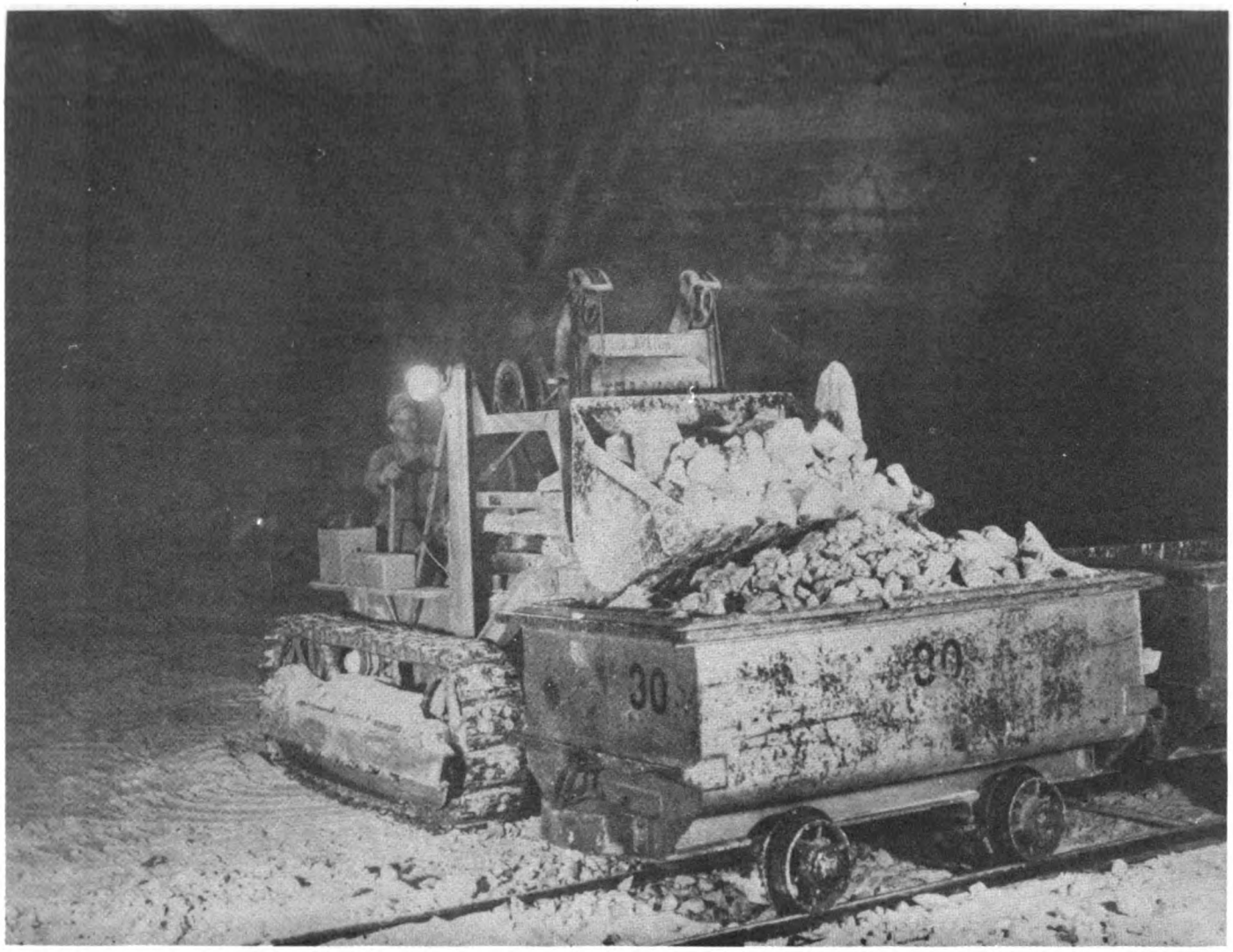

Figure 13. - Loading gypsum with a Diesel-powered unit. This type of equipment is used frequently for clean-up purposes.

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2. That automatic carbon-monoxide detectors equipped with bells capable of being heard throughout the work area be installed where Diesel trucks are used. Upon sounding an alarm indicating dangerous concentrations of carbon monoxide, that portion of the mine is to be vacated until the atmospheric condition returns to normal.
3. That the department reserves the right to require any additional safeguards deemed necessary for the safe operation of the mine, after investigations during actual operating conditions.

The limestone bed is 21 feet thick, 17 feet being mined; the remaining 4 feet are left as a roof. The rooms and entries are driven about 30 feet wide on 60-foot centers. Pillars are not recovered.

Ventilation is by natural means; there are 12 adit openings to the mine, which provide for all necessary ventilating requirements. Measurements taken along the haulageway show a movement of air of 33 linear feet a minute in a cross-sectional area of 561 square feet, or somewhat less than 19,000 cubic feet per minute.

The broken limestone is loaded by an electric shovel equipped with a tunnel-type boom and mounted on caterpillars. The rock is loaded into tractor-trailer-type trucks and hauled to the crushing plant. The round trip is approximately 4 miles, of which 2-1/2 miles is underground and 1-3/4 miles is on the surface.

The Diesel truck engine is a 6-cylinder turbulence-controlled-type; the cylinders have a bore of 3-3/4 inches with a 4-1/2-inch stroke. The displacement is 298 inches and the brake horsepower at 2,500 r.p.m. is 85. The exhaust from the engine is carried to the atmosphere through a pipe that extends from the engine to the top of the trailer, which tends to keep the exhaust gas away from the driver of the truck. The engines are stopped while the trucks are being loaded. The Diesel engines are overhauled at the factory after being used for 20,000 miles; the pistons, piston rings, and cylinder sleeves are renewed in the general reconditioning of the engines.

Samples of the general mine air were analyzed as follows:

	No. 15 entry		Main haulage road	Face of entry at shovel
	1	2	3	4
Oxygen	20.76	20.79	20.73	20.90
Nitrogen	79.04	79.00	79.21	79.01
Carbon dioxide	.21	.21	.06	.08
Carbon monoxide	.00	.00	.00	Less than 0.01
Methane	.00	.00	.00	.00
	100.00	100.00	100.00	100.00

The oxides of nitrogen were not determined.

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Supersensitive carbon monoxide indicators were operated in the haulageway, at a working face, and in a caved area, but no carbon monoxide was detected by the indicator. The supersensitive carbon monoxide indicator accurately determines carbon monoxide in the range of 0.01 to 0.001 percent.

Diesel Trucks Working in a Shaft Mine in Ohio

An Ohio limestone mine, which is opened by two shafts 2,200 feet deep, is using six Diesel-powered trucks of 6 cubic yards capacity each for haulage units and a Diesel-powered bulldozer for clean-up purposes. The two-entry room-and-pillar method of mining is used to extract a 17-foot approximately horizontal bed of limestone at the 2,250-foot horizon. The entries are driven about 16 feet wide and 17 feet high; the rooms are advanced about 30 feet wide and 17 feet high for a distance of 600 feet. On retreat, an additional 12 feet of top rock is mined, making the final room about 30 feet wide and 29 feet high. The pillars are not recovered.

Ventilation is induced by a reversible fan operating blowing. About 66,000 cubic feet of air per minute is circulated through the mine in two splits. The haulageways are ventilated by return air when it is possible to do so.

The trucks are powered by 2-cycle, 4-cylinder Diesel engines with 4-1/4-inch bore and 5-inch stroke. The engines develop 107 horsepower at 1,800 r.p.m. The trucks are fitted with a 3-speed transmission and a reverse gear, which gives the trucks three speeds in either direction. The trucks have been in service since 1941.

The bulldozer is powered by a 2-cycle, 3-cylinder Diesel engine with 4-1/4-inch bore and 5-inch stroke. The governed maximum speed of 1,500 r.p.m. develops a drawbar horsepower of 60.1.

A Diesel tractor equipped to load material is used as an auxiliary rock-loading unit. The engine is a 4-cycle, 6-cylinder type that develops 61.2 horsepower at 1,200 r.p.m.

A 1-1/2-ton truck fitted with a 4-cylinder, 4-cycle Diesel engine that develops 70 horsepower at 2,600 r.p.m. is used as a service truck.

The large trucks are loaded by an electric shovel or the Diesel tractor and transport the limestone to the hoisting shaft. It requires 7 to 10 minutes to make a round trip; each truck makes 30 to 40 round trips a shift. The truck engines are stopped while the truck is being loaded; they are repaired at irregular intervals; the last general overhaul of equipment was in December, 1945 and this study was made in June 1946.

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Samples of the general mine air had the following analysis:

Sample location	Face of Room A	Face of Room B	Main return at shaft bottom. Three Diesel trucks had passed in haulageway in preceding 7 minutes
Oxygen	20.92	20.72	20.92
Nitrogen	79.02	79.08	79.02
Carbon dioxide	.06	.16	.05
Carbon monoxide	.00	.00	.00
Methane	.00	.04	.03
Oxides of nitrogen	-	-	-

Samples of the exhaust gas[25] were taken from five of the six Diesel-powered trucks; the samples were taken while the engines were idling and under varying load conditions. The analyses of these samples follows:

Trucks idling

	Truck 1	Truck 2	Truck 3	Truck 4	Truck 5
Oxygen	19.63	19.67	19.63	19.90	19.85
Nitrogen	79.39	79.41	79.40	79.24	79.29
Carbon dioxide	.90	.89	.89	.82	.80
Carbon monoxide	.05	.03	.03	.04	.04
Methane	.03	.00	.05	.00	.02
	100.00	100.00	100.00	100.00	100.00
Oxides of nitrogen, parts per million	40	64	20	33	13
Aldehydes, parts per million.	47	30	40	40	40

Trucks working under varying loads

	Truck 1	Truck 2	Truck 3	Truck 4	Truck 5
Oxygen	15.20	16.87	14.98	18.25	11.55
Nitrogen	80.64	80.17	80.63	79.74	81.67
Carbon dioxide	4.11	2.93	4.31	1.98	6.68
Carbon monoxide	.05	.03	.05	.03	.07
Methane	.00	.00	.03	.00	.03
	100.00	100.00	100.00	100.00	100.00
Oxides of nitrogen, parts per million	-	175	43	37	46

Remarks

The successful use of Diesel-powered equipment at this mine is significant. The mine shaft is 2,200 feet deep, and ventilation of the working places is induced by mechanical methods. The volume of fresh air taken into the mine is sufficient to dilute and carry away the toxic gases of the exhaust

25/ Unpublished report by L. B. Berger, R. T. Artz, and R. F. Davis.

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from the Diesel engines, and analyses of the samples of the general air indicate that the air in this mine is better than ordinarily is found in mines, notwithstanding the use of seven different units of Diesel-powered equipment.

The amount of toxic gases found in the exhaust of the Diesel engines is relatively small probably because of their good mechanical condition, and this definitely supports the idea that maintenance of Diesel equipment is of prime importance, particularly when the equipment is used underground.

Diesel-powered Truck Used Underground in the Tri-State Lead-Zinc District

A Diesel-powered truck is used as a haulage unit underground in a zinc mine in the Tri-State district of Kansas, Missouri, and Oklahoma. The truck was placed in service in January 1946, and the mine air as well as the exhaust of the Diesel engine have been tested at approximately 3-month intervals.

The mine is opened by four vertical shafts; the main shaft is 332 feet deep. Mining is on the advance, with only one level working. The open-stope-and-pillar method of mining is used; the pillars are approximately 20 feet in diameter, spaced on about 60-foot centers. The roof or back of the stope is approximately 14 feet above the floor; the stoped area is, roughly, 1,300 feet long and averages 55 feet in width.

The ore is loaded into trucks by a 3-drum, electric-powered hoist and an inclined portable ramp and is transported to the hoisting shaft. The trucks are 5-ton, rubber-tired, dump-body type powered with storage batteries, except one, which has a Diesel engine. The Diesel truck has the following specifications:

Type	4-cycle, overhead-valve
Number of cylinders	4
Cylinder bore, inches	4-7/8
Piston stroke, inches	6
Rated horsepower	100
Piston displacement, cubic inches	448
Developed horsepower	70
Maximum rated speed (governed), r.p.m.	1,800

The exhaust pipe of the engine passes through the hood and extends toward the rear of the truck, past the driver. A special device has been installed on the truck engine by the mining company to lessen or remove the carbon monoxide from the exhaust gas; the description of this device has not been released by the company pending patent proceedings.

The general mine air in the vicinity of the loading operations was analyzed prior to starting the Diesel truck as one of the haulage units. These analyses are tabulated below:

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	Sample		
	1	2	3
Oxygen	20.75	20.70	20.85
Nitrogen	79.07	79.12	79.05
Carbon dioxide	0.08	0.18	0.10
Carbon monoxide	0.00	0.00	0.00
Methane	0.00	0.00	0.00
	100.00	100.00	100.00
Oxides of nitrogen, parts per million	0	0	0

Mechanical means of ventilating mines are not used, and no attempt is made to control the natural ventilating currents. Air measurements taken at various times show that a considerable volume of air moves through the mine workings; the measurements indicate that the air currents range from 20,000 to 60,000 c.f.m.

The average time required for the truck to be loaded, dumped and to travel was 5 minutes; the engine was allowed to idle while the truck was being loaded, but the idling time generally was less than 2 minutes. The round trip traveled by the truck was approximately 0.2 mile.

Samples of the general mine air taken after the slusher had completed loading the Diesel truck, and with the engine idling, had the following analyses:

	1	2	3	4
Oxygen	20.81	20.78	20.92	20.91
Nitrogen	79.12	79.05	79.02	79.03
Carbon dioxide	.07	.17	.06	.06
Carbon monoxide	.00	.00	.00	.00
	100.00	100.00	100.00	100.00
Oxides of nitrogen, parts per million	0	0	0	0

A 10-ton, 2-wheel, hydraulic-lift dump trailer was substituted for the 5-ton hopper-bottom truck body after about 6 months of service. The loading, dumping, and travel time for the new unit was 9 minutes, of which 4-1/2 minutes were spent in loading while the engine was allowed to idle.

Samples of the general mine air taken at the end of the loading cycle, while the engine was idling, had the following analysis:

	1	2
Oxygen	20.89	20.88
Nitrogen	79.04	79.00
Carbon dioxide	0.07	0.12
Carbon monoxide	0.00	0.00
	100.00	100.00
Oxides of nitrogen, parts per million	0	22

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Samples of the exhaust gas from the Diesel engine were taken from inside the exhaust pipe 18 inches from the pipe outlet. The analyses of these samples are shown below:

Samples of Diesel engine exhaust gas taken 18 inches from pipe outlet

	Engine idling	Engine, maximum throttle	Engine, normal high-speed gear
Oxygen	20.19	15.54	15.59
Nitrogen	79.06	80.39	80.39
Carbon dioxide	.73	3.98	3.96
Carbon monoxide	.02	.05	.06
Methane	.00	.04	.00
	100.00	100.00	100.00
Oxides of nitrogen, parts per million	39	26	60

Remarks

The introduction of Diesel trucks into the lead-zinc mines of the Tri-State district is of interest. The large open stopes and numerous mine shafts, although not providing positive ventilation, should prove to be satisfactory, as the air movement in one direction or another generally should be sufficient to dilute and ultimately carry away the exhaust gas from the Diesel engine.

Diesel-driven Mining Equipment Underground in Missouri

An underground limestone and shale mine in Missouri is using internal-combustion engines as power units for most of the underground operations other than loading rock. The use of Diesel-powered portable air compressors and drill jumbos mounted on Diesel caterpillar tractors is unusual. Three trucks used for haulage purposes, however, are equipped with gasoline engines, and one truck is Diesel-engine-powered.

The mine is opened by two adits and covers an area of approximately 80 acres. The limestone formation is virtually level and is overlain with beds of shale and limestone. The cover over the mine workings averages approximately 100 feet in thickness.

The mining method consists of driving rooms about 38 feet wide between staggered pillars roughly 55 feet square. The rooms are driven essentially 18 feet high; all mining in limestone is worked advancing. The shale that overlies the limestone is mined by blasting 18 feet of shale into the rooms where limestone mining is completed or abandoned temporarily. Shale mining is worked on the retreat. Approximately 800 tons of rock is mined daily.

Mechanical ventilation is not provided, but natural ventilation is assisted with two vertical circular shafts, concrete-lined; one shaft is 14 feet in diameter and the other is 7 feet. Considerable air movement in the mine workings is induced by the piston effect of the large trucks moving

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through the relatively narrow haulageways. The air measurements taken indicate that approximately 20,000 cubic feet of air per minute is circulating through the working sections of the mine.

Portable air compressors of 350 and 500 c.f.m. capacity are powered by Diesel engines. Drill jumbos are mounted on Diesel caterpillar tractors and are moved from one working place to another as required. In moving, the Diesel tractor pulls the portable compressor to the new working place, and the compressor is left a convenient distance from the face, generally in a crosscut between two pillars.

Electric-powered shovels load the broken rock into 15 cubic yard-capacity, 10-wheel trucks, which transport the rock to the crushing plant. The roads are fairly level and are well-maintained; water is used to allay the dust on the roads. Three trucks are equipped with gasoline engines and one truck with a Diesel engine.

The general mine air along the haulageways and in the vicinity of the working places was sampled with vacuum tubes and by using a supersensitive carbon monoxide indicator. The concentration of carbon monoxide was not sufficient to be indicated on the detector. The analyses of the air samples are shown below:

	About 150 feet from 350 c.f.m. portable air compressor	Near 500 c.f.m. portable air compressor	At face of room, electric shovel operating
Oxygen	20.76	20.81	20.87
Nitrogen	79.08	79.07	79.03
Carbon dioxide ..	.01	.11	.09
Carbon monoxide .	.00	Less than .01	Less than .01
	100.00	100.00	100.00
Oxides of nitrogen, parts per million	12	-	-

Remarks

The general mine atmosphere is virtually normal air, and in quality it appears to be better than is usually found in underground mines.

The use of Diesel-powered portable air compressors underground is unusual, but in this case it appears to be satisfactory, inasmuch as the analyses show that the general mine air in the immediate vicinity of the operations is better than is usually found in the air of mine workings. The use of this equipment could be made safer from possible concentrations of toxic gases if a portable fan were installed with the unit to insure dispersal of the exhaust gases and to assist in the general air movement in the mine.

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The use of gasoline engines underground is considered hazardous by the Bureau of Mines; the gasoline-engine exhaust contains much more carbon monoxide than the exhaust from a Diesel engine, and in addition the fire as well as the explosion hazard of gasoline is much greater than when the less flammable fuel oil is used in Diesel engines.

DIESEL LOCOMOTIVES IN A RAILROAD TUNNEL

The large increase in the number of railroad-type Diesel locomotives used on American railroads has created interest in their safety in some of the long mountain tunnels. Upon request, the Bureau of Mines made a study of conditions found in one western railroad tunnel.[26]

The tunnel is 7.79 miles long; it is single-track, straight, concrete-lined, and is on an essentially uniform grade of 1.56 percent, ascending from west to east. The cross-sectional area of the tunnel is 314 square feet; the east portal is at an altitude of 2,880 feet and the west portal is at 2,240 feet.

The Diesel locomotive is of conventional design and consists of four units, each of which contains an engine coupled directly to a 600-volt, direct-current, generator supplying power to the driving wheels of the unit. The engines are V-type, two-stroke cycle, having 16 cylinders of 8-1/2-inch bore and 10-inch stroke with a piston displacement of 9,079 cubic inches. Each engine develops 1,570 horsepower at a maximum speed of 800 r.p.m. Each unit of the locomotive is rated normally at 1,350 horsepower, which is understood to represent the power output of the generator. The locomotive was 9 feet, 11-1/4 inches wide over all and 15 feet, 1/8 inch in over all height above the rails.

At the time of the investigation, eight passenger trains were scheduled to pass through the tunnel daily, and freight trains averaged 7 per day. Freight movements were irregular, but four passenger trains passed through the tunnel each way between midnight and 4 p.m.

Some of the results of this investigation are of interest to users of Diesel mine locomotives and Diesel trucks underground; these are summarized below:

1. Trains passing through the tunnel created air movement in the same direction as train movement, the velocity of the air thus created being somewhat less than train speed. Under typical operating conditions, approximately 50 percent of the air in the tunnel was forced out of the tunnel ahead of the train, and 50 percent of the air slipped back past the train through the space between the train and tunnel walls, roof, and floor.

26/ Berger, L. B., and McGuire, L. H., Observations on the Use of a Diesel Freight Locomotive Through a Railway Tunnel: Bureau of Mines Rept. of Investigations 3887, 1946, 20 pp.

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2. Under typical operating conditions, the Diesel locomotive was found to leave behind it in the tunnel a wake of smoke and gases some 20,000 feet in length.

3. The exhaust gases of the Diesel did not produce hazardous concentrations of carbon dioxide, and the oxygen content of the tunnel was not depleted significantly. The maximum observed concentration of carbon monoxide was only slightly above 0.01 percent, the maximum generally considered permissible in the air of working places. Oxides of nitrogen were found in a considerable area behind the train in concentrations exceeding 25 parts per million (the permissible maximum), which, under conditions of minimum air movement, might affect persons at work in the tunnel; this applied only to the eastbound or upgrade trains. No significant contamination of the tunnel air by oxides of nitrogen or other gases was observed as a result of westbound or downgrade trips.

4. Smoke from the Diesel locomotive definitely reduced visibility in the tunnel.

5. Natural air movements in the tunnel may be in either direction, depending on atmospheric conditions, and under some conditions there might be no natural air movement at all.

CALCULATION OF THE MINIMUM AMOUNT OF VENTILATING AIR REQUIRED TO OPERATE A DIESEL ENGINE UNDERGROUND

Ventilation requirements and procedures for safe operation of Diesel engines underground in a mine or tunnel are of considerable importance and should be given careful consideration before a Diesel engine is permitted to operate in mines or tunnels. This is important not only from a health standpoint but also for engine efficiency, as virtually normal air is required for maximum efficiency in the performance of a Diesel engine underground.

There are two principal methods of determining the amount of ventilating air required to operate a Diesel engine safely underground; both of these methods are shown in Bureau of Mines publications[27/], [28/] and are discussed here.

Method 1

Diesel engines, when in good mechanical condition and operating in normal air, give off noxious gases in the exhaust, and the quantities increase in amount with the brake horsepower of the engine. At full speed and maximum load, the tests made by the Bureau of Mines[28/] and other sources show that the following amounts of noxious gases are produced per brake horsepower by a Diesel engine:

27/ See footnote 4.
28/ See footnote 5.

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	Cubic foot
Carbon dioxide	0.267
Carbon monoxide	0.000592
Oxides of nitrogen	0.001512

Upon this basis, it has been determined[28] that approximately 75 cubic feet of air per minute per brake horsepower is required for each Diesel engine operating underground; this is the minimum requirement and is in addition to the normal ventilation supplied to the working place if Diesel engines are not used; additional volumes of air are required to dilute the aldehydes to prevent undue occurrence of undesirable though harmless odors.

Method 2

From studies made of Diesel engines under various conditions and from analyses of the exhaust gas it has been observed that the maximum volumes of noxious gases are found in the Diesel exhaust when the engine is working under maximum load at full speed. The percentage of the constituent gases in the exhaust may fluctuate higher or lower when the engine is operating at less than this maximum condition, but the volume of the gas produced is greatest when the engine is operating under maximum load at full speed. The volume of noxious gases evolved by the engine can be calculated from analyses of the exhaust gas, and the maximum amount of these gases considered tolerable for a working environment has been established at least tentatively.

Through data collected and observations made on Diesel locomotives working underground, Bureau of Mines engineers developed a method of determining the amount of ventilating air required in operating a Diesel engine underground,[27] using as a basis the analysis of the exhaust gas and the maximum concentration of noxious gases considered safe for a working environment. The quantity of air that should be supplied to dilute a particular constituent of the exhaust gas can be approximated by substituting in the following empirical formula:

$$Q = \frac{100\ Vmax}{y}$$

in which Q = volume of normal air required for ventilation, cubic feet per minute.

Vmax = maximum volume of the particular constituent under consideration, cubic feet per minute.

y = maximum permissible concentration of the particular constituent under consideration, expressed in percent by volume.

The engineers that developed the formula suggest that the maximum quantity of each constituent of the exhaust gas produced per unit of time be used in calculating ventilating-air requirements. In practice this is difficult to do, as analyses of exhaust gas under various conditions generally

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are not made prior to installation of the unit, and manufacturers of the equipment do not publish such information.

The exhaust of a Diesel engine is a mixed gas, and the constituents that are considered harmful to health are carbon dioxide, carbon monoxide, and oxides of nitrogen, hence, there must be sufficient ventilating air to dilute and carry away all of these. In addition, there are nontoxic gases called aldehydes with odors that are irritating to some people. The formula as related to the toxic constituents of the exhaust becomes:

$$\text{Minimum quantity of ventilating air, cubic feet per minute} = \frac{100\ V_{max}}{y}\ (\text{carbon dioxide}) + \frac{100\ V_{max}}{y}\ (\text{carbon monoxide}) + \frac{100\ V_{max}}{y}\ (\text{oxides of nitrogen})$$

In addition to the minimum, as obtained from the formula, enough air must be supplied to dilute the odors from the aldehydes and to maintain a sufficient amount of oxygen in the general atmosphere.

Example:

The following analyses of exhaust gas from a Diesel engine working in an American mine are selected as representative. Case 1 shows the analysis of the exhaust when the engine is working under the maximum load at this mine, and case 2 shows the analysis when the engine is working but is not under maximum load.

Engine specifications

Cylinders	6
Cylinder bore, inches	4-1/4
Piston stroke, inches	5
Piston displacement, total, cubic inches	425.3
Maximum rated horsepower	165 at 2,000 r.p.m.

Method 1

Maximum brake horsepower - 165
75 cubic feet of ventilating air per minute per brake horsepower
Minimum ventilating air required = 165 x 75 = 12,375 cubic feet per minute.

Method 2

Analyses of Diesel-engine exhaust

	Case 1	Case 2
Condition	Hauling out loaded trip, 21 cars	Hauling in empty trip, 21 cars

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Analysis, percent by volume:

Oxygen	13.04	13.66
Carbon dioxide	5.88	5.32
Carbon monoxide	0.09	0.03
Methane	0.03	-
Nitrogen	80.96	80.99
	100.00	100.00
Oxides of nitrogen, parts per million	295	257

Total piston displacement is 425.3 cubic inches
R.p.m. is 2,000

Volume of exhaust gas, cubic feet per minute = $\frac{425.3 \times 2,000}{1,720}$ = 493 cubic feet.

Case 1:

When the locomotive was working at maximum load

Volume of carbon dioxide produced per minute = 493 x 0.0588 = 28.988 = 29 cu. ft.
Volume of carbon monoxide produced per minute = 493 x 0.0009 = 0.4437 = 0.44 cu. ft.
Volume of oxides of nitrogen produced per minute = 493 x 0.000295 = 0.14543 = 0.145 cu. ft.

The maximum permissible concentration of noxious gas in a working environment, as shown in Schedule 22, issued by the Bureau of Mines, is:

	Percent	Parts per million
Carbon dioxide	1.0	10,000
Carbon monoxide	0.01	100
Oxides of nitrogen	0.0025	25

Substituting in the formula:

	Carbon dioxide	Carbon monoxide	Oxides of nitrogen
Minimum quantity of ventilating air, cubic feet per minute	$= \frac{100 \times 29}{1.0}$	$+ \frac{100 \times 0.44}{0.01}$	$+ \frac{100 \times 0.145}{0.0025}$
	= 2,900	+ 4,400	+ 5,800

= 13,100 cubic feet of air per minute.

It is noticeable that the result, as computed under method 1 (12,375 cu. ft. per minute) approximates fairly closely the result obtained from method 2 (13,100 cu. ft. per minute) when the locomotive was working under full load.

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Case 2:

When the locomotive was working but not under maximum load

Volume of carbon dioxide produced per minute = 493 x 0.0524 = 25.7 cu. ft.
Volume of carbon monoxide produced per minute = 493 x 0.0003 = 0.1479 = 0.148 cu. ft.
Volume of oxides of nitrogen produced per minute = 493 x 0.000257 = 0.1267 = 0.127 cu. ft.

	Carbon dioxide	Carbon monoxide	Oxides of nitrogen
Minimum quantity of ventilating air, cubic feet per minute	$= \frac{100 \times 25.7}{1.0}$	$+ \frac{100 \times 0.148}{0.01}$	$+ \frac{100 \times 0.127}{0.0025}$
	= 2,570	+ 1,480	+ 5,080

= 9,130 cubic feet of air per minute.

The result (9,130 cubic feet of air per minute) obtained from method 2, when the locomotive was not working under full load, indicates that if the quantity of air necessary for full-load operation is supplied (13,100 cu. ft. per minute), there would be a fair factor of safety for conditions of part-load operation.

Case 2 illustrates the desirability of selecting analyses of the exhaust gas when the engine is working under the maximum load it will be required to handle under actual working conditions, as the maximum volumes of noxious gases are produced when the engine is working under maximum load at full speed, and it is necessary to supply enough air to safeguard the working atmosphere under the most unfavorable condition of operation.

Blasting in a mine produces carbon dioxide, carbon monoxide, and generally some oxides of nitrogen; allowance should be made for these variables when calculating the ventilating requirements before installing any Diesel equipment underground. The formula for the minimum requirement of ventilating air when operating a Diesel engine underground is based upon normal air, which is seldom found in a mine. The calculated minimum quantity of ventilating air required should be increased to allow for these variables as well as for the aldehydes and the relatively slight amount of oxygen consumed by the Diesel operation.

Air in the place where a Diesel engine is operating should be analyzed frequently. It is particularly important that this be done immediately after Diesel equipment has been installed, as it will provide information as to the quantity of air required to avoid trouble.

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MINING LAWS RELATIVE TO THE USE OF INTERNAL-COMBUSTION ENGINES UNDERGROUND

The mining laws and regulations of some States prohibit the use of internal-combustion engines in underground mines; other States permit their use, provided permission to install them is first obtained from the Department of Mines. This applies to both coal and noncoal mines.

Bureau of Mines Information Circular 7333, Inspection Standards For Bituminous-Coal and Lignite Mines (revised July 1945), states:

"8.34 - Nonpermissible internal-combustion engines should not be used underground."

The laws and regulations prohibiting the use of internal-combustion engines underground are intended primarily to prevent the use of gasoline engine-powered mine locomotives and other equipment. Many of these laws and regulations were in effect before the Diesel engine was perfected to its present stage of safety and efficiency and was fairly generally adopted for haulage purposes in foreign countries. At present in England, Diesel locomotives may not be used underground without permission from the Ministry of Mines.

Although the Bureau of Mines issued its testing schedule for Diesel locomotives for use in gassy or dusty coal mines in the fall of 1944, no Diesel mine locomotives were submitted to the Bureau for test for permissibility up to February, 1947. Hence, it is very important that competent authorities, such as the State Mine Inspection Department or the Bureau of Mines, review the plan for each installation of a Diesel locomotive underground before it is actually placed in service. This is necessary to insure adequate ventilation in metal and coal mines as well as to insure against possible gas ignition in coal mines, and it should be done even though the available locomotives are permissible.

It is believed that in the future Diesel-powered mine locomotives that can be rated "permissible" by the Bureau of Mines will be manufactured in the United States, similar to those now manufactured in England that possess the Buxton certificate.

HAZARDS OF TROLLEY LOCOMOTIVES IN COAL MINES COMPARED WITH THOSE OF DIESEL MINE LOCOMOTIVES

For many years the United States Bureau of Mines took a firm stand against the use of internal-combustion engines in underground workings, and several of the States enacted laws, which are still in effect, prohibiting such use. This opposition resulted from the fact that many lives were lost through fires, explosions, and suffocations when internal-combustion engines were used underground in connection with the operation of locomotives, trucks, air compressors, pumps, hoists, etc., using gasoline-driven engines. With the advent of the use of Diesel engines in European mines in the 1920-1930 decade, the Bureau of Mines kept fairly close watch of progress in the

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use of Diesel equipment underground. The Bureau became acutely aware, also, of the increasing hazards of the trolley locomotive system in the mines of the United States, as shown by the fast growing number of casualties due to the trolley system, and in 1932 it defined its attitude toward the use of Diesel equipment for haulage in mines in the United States in Mine Safety Board Decision No. 19, issued in 1932, which is as follows:

Decision 19, internal-combustion engines for mine haulage (approved Jan. 20, 1932):

In the interest of safety, the United States Bureau of Mines recommends that:

1. Internal-combustion engines should not be used in any parts of mines and also should not be used in tunnels under construction because of the hazard of carbon monoxide in the exhaust gases, except

(a) When the air current is more than 100 linear feet per minute and the toxic gases are always less than 0.02 percent in the air current.
(b) When the percentage of inflammable gas in the air current is less than 0.25 percent and (or) inflammable gas cannot be detected in any place by a permissible flame safety lamp.

2. Gasoline or other highly inflammable liquids should not be used for engine fuel in mines and in tunnels under construction because of the hazard of their transportation and use.

Decision 19 was published in Bureau of Mines Information Circular 6946 (issued in June 1937), entitled "Recommendations of the United States Bureau of Mines on Certain Questions of Safety as of October 1, 1936," in which the following comment occurs:

Diesel Mine Locomotives

Although in mine and tunnel haulage it is safer to employ "permissible" storage-battery locomotives, if the ventilation requirements are met and other precautions are taken it appears, from recent European experience, to be safe to employ approved types of Diesel locomotives that use a heavy, nonvolatile fuel oil, give off practically no carbon monoxide in their exhaust, and have spark- and flame-arresting devices both in their air intake and their exhaust systems.29/ Such locomotives have been approved by the German, French, and Belgian official stations for use in gassy mines. None, however, have as yet

29/ Rice, George S., and Harris, F. E., Diesel Mine Locomotives - Development and Use in European Coal Mines: Bureau of Mines Rept. of Investigations 3320, 1936, 52 pp.

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(October 1, 1936) been submitted to the United States Bureau of Mines for testing for permissibility, and none have been used in underground mines in the United States so far as known.

The above was the official announcement of the fact that the United States Bureau of Mines favored the use of suitably designed Diesel locomotives for underground haulage in mines and tunnels. This change in the stand of the Bureau as to the use of internal-combustion engines underground, insofar as suitably designed Diesel locomotives are concerned, was brought about largely by the ever growing number of fatalities caused by the trolley haulage system in the mines of the United States plus the fact that available data from Europe indicated the relatively safe and efficient use of Diesel locomotives in Continental European mines, including those having serious gas and dust hazards.

Inspection Standards for Bituminous-Coal and Lignite Mines (revised July 1945), issued by the Bureau of Mines as Information Circular 7333, has the following under Haulage Equipment: "Nonpermissible internal-combustion engines should not be used underground," indicating that permissible internal-combustion engines are acceptable. The Bureau of Mines, in September 1944, issued Schedule 22, entitled "Procedure for Testing Diesel Mine Locomotives for Permissibility, and Recommendations on the Use of Diesel Locomotives Underground;" however, up to February 1, 1947, no Diesel locomotive has been offered to the Bureau of Mines for test and permissibility approval.

However, it is known that Diesel locomotives used in underground mines, like all kinds of equipment placed in mines, also bring their own hazards, which were not present before they were installed. The chief additional hazard in the operation of Diesel engines underground, however, is the presence of toxic gases in the exhaust; these can be controlled and virtually eliminated by using suitably constructed and well-maintained Diesel locomotives and by providing adequate ventilation. On the other hand, the trolley-locomotive system has numerous inherent hazards that are not susceptible of control.

In order to indicate, at least in part, why the Bureau of Mines approves the use of Diesel locomotives rather than the trolley haulage system, some of the hazards of the trolley system are numerated below:

1. Contact of persons with bare trolley wire.
2. Contact of bare trolley wire with mine doors, timbering, roof, ribs, and curtains (fire hazard).
3. Arcs or sparks from poor or broken bonding, bad joints, or broken rails igniting coal or gas or timber ties.
4. Arcs or sparks from trolley wheel, harp, or shoe igniting combustible material such as brattice cloth, wood, gas, or dust.
5. Arcs or sparks from locomotive controller or motor igniting gas or dust.

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6. Arcs or sparks from locomotive wheels on poorly bonded track.
7. Falls of roof, bringing down trolley wire and touching cars or rail, igniting coal or gas.
8. Wrecked or derailed cars, causing coal dust to be thrown into suspension and ignited by arcs from the fallen trolley wire.
9. Explosions of Cardox shells, explosives, etc., through short circuits on trolley haulage trips or cars.
10. Stray currents from poorly installed trolley system causing premature detonation of electrically fired explosives.30/

The relatively large number of electrical contact accidents in coal mines is shown in table 6.28/

TABLE 6. - Electrical contact accidents in coal mines, 1929-42

Year	Bituminous				Anthracite			
	Fatalities		Nonfatalities		Fatalities		Nonfatalities	
	Trolley wires and locomotives	All elec. causes	Trolley wires and locomotives	All elec. causes	Trolley wires and locomotives	All elec. causes	Trolley wires and locomotives	All elec. causes
1930	42	63	467	1,237	5	8	126	336
1931	41	62	311	910		3	78	253
1932	31	42	238	651	3	5	59	202
1933	32	46	246	652	5	7	68	174
1934	43	53	208	589	1	3	43	151
1935	33	43	180	601		2	49	169
1936	31	44	185	587	3	8	25	130
1937	36	52	263	754	1	4	113	288
1938	26	38	166	540	2	2	72	151
1939	28	49	205	574	1	2	50	211
1940	19	30	243	756	3	7	49	153
1941	31	42	220	739	5	5	56	94
1942	35	51	155	931	2	6	41	141
Total	428	615	3,087	9,521	32	62	877	2,453

Table 6 indicates that for the period 1930-42, inclusive, 428 fatalities due to contact with electricity out of a total of 615 (nearly 70 percent) in the bituminous coal mines of the United States were caused by the trolley locomotive system, and 32 out of 62 (nearly 50 percent) of the electrical contact fatalities in anthracite coal mines were caused by the trolley system.

30/ Harrington, D., and Warncke, R. G., Hazards of the Trolley-Locomotive Haulage System in Coal Mines: Bureau of Mines Inf. Circ. 7328, 1945, 38 pp.

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Fire is an ever-present hazard in a coal mine and is especially dangerous to handle because of the possibility of an explosion. The combustible nature of coal and of the materials used for extracting coal, such as timber, explosives, and other flammable substances, as well as the constantly increasing use of electrical equipment with its ever-present sources of ignition, tend to make fire a constant threat in all coal-mine operations. Relatively few fires are called to the attention of the outside world, for, unlike mine explosions, which generally cause loss of life, fires usually result in few fatalities, although they always present the possibility of a disaster, and generally the dollars and cents cost is high. One of the most prolific causes of mine fires is the trolley locomotive system, with its numerous capabilities for starting fires.

Statistics relative to coal-mine fires caused by trolley wire or trolley locomotive from 1930 to 1944 are given in table 7.

TABLE 7. - Coal-mine fires caused by trolley wire or locomotives, 1930-44; comparisons with total electrical causes and total of all causes

Year	Trolley-locomotive system		Total electrical causes		Total all causes	
	No.	Fatalities	No.	Fatalities	No.	Fatalities
1930	5	2	8	2	19	4
1931	2	0	7	0	21	7
1932	0	0	5	1	17	1
1933	1	0	7	0	20	1
1934	1	0	4	0	18	6
1935	2	0	11	11	17	11
1936	3	0	7	1	16	4
1937	2	1/9	5	9	15	11
1938	2	0	6	1	20	4
1939	1	0	7	1	15	2
1940	0	0	5	2	16	2
1941	1	1	7	2	13	2
1942	3	1	9	4	26	21
1943	3	13	6	13	21	15
1944	6	2/22	9	22	24	24
Total.	30	48	103	69	278	115

1/ 9 men overcome with carbon monoxide while attempting to seal the fire.

2/ 16 men killed by explosion while fighting fire.

Trolley-locomotive systems caused 30 coal-mine fires out of a total from all causes of 278 during the period 1930-1944, or 10.8 percent of the total. Fatalities attributable to the trolley-locomotive systems were 48, or 41.7 percent of the total of 115 during the same period.

Two major accidents, one in which 9 men were overcome with carbon monoxide in 1937 and another in which 22 men were killed by an explosion in

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1944, serve to emphasize the ever-present danger to the men engaged in combating mine fires.

The coal-mining industry recognizes the danger of explosions in mines caused by gas or coal dust, but frequently the possible causes of explosions are overlooked in the necessity for producing larger tonnages of coal, especially during rush seasons or in emergencies such as the recent war. Many people do not realize that the trolley-locomotive system was the cause of 13.5 percent of coal-mine explosions in the United States from 1930 to 1944, inclusive. Table 8 gives these statistics by years.

TABLE 8. - Explosions caused by trolley wires and locomotives, 1930-44; comparisons with total electrical causes and total of all causes

Year	Trolley-locomotive system		Total electrical causes		Total, all causes of explosions	
	Number	Fatalities	Number	Fatalities	Number	Fatalities
1930	6	26	18	154	34	199
1931	3	84	9	143	26	217
1932	2	2	10	11	33	87
1933	4	6	8	25	22	122
1934	5	13	10	21	26	28
1935	3	1	10	29	22	54
1936	2	10	5	20	25	38
1937	5	25	12	53	20	62
1938	4	16	10	24	29	170
1939	3	7	9	13	14	16
1940	0	0	6	99	18	206
1941	4	73	14	145	26	163
1942	3	9	14	133	22	152
1943	1	20	19	66	32	152
1944	5	15	11	59	20	94
Total ...	50	307	165	995	369	1,760

One cause for the large number of Diesel locomotives used in Europe and England is restrictive legislation that prevents the use of electricity in underground gassy coal mines; compressed air-operated machinery, such as compressed-air locomotives and shaker conveyors with compressed-air motors, is commonly used. With the improvement of the Diesel engine in recent years, this type of haulage unit is replacing the slower and more restricted compressed-air locomotives. The increase in number of mine locomotives used underground in some European countries has been entirely in the Diesel-powered types; the number of electric-type locomotives remained substantially the same. Mining officials in Continental Europe have stated[31] that they favor the use of Diesel engines over trolley locomotives because they are fearful of explosions and fires with use of trolley locomotives. The record shown in table 3 appears to bear out their convictions as to the dangers inherent in the trolley system when used in coal mines.

31/ See footnote 19.

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Statistics are not available covering accidents, mine fires, and explosions in European mines caused by Diesel mine locomotives, but so far as can be ascertained, the Diesel mine locomotive has caused few if any mine fires or explosions; moreover, it is not known to have been responsible for any fatal accidents from toxic gases in the exhaust. On the other hand, careful analysis of tables 6, 7, and 8 shows that in the 15-year period 1930 to 1944, inclusive, 428 persons were killed in the mines of the United States by contact with electricity in trolley wires and locomotives, 48 were killed by fires caused by the trolley locomotive system, and 307 were killed by explosions caused by trolley wires and locomotives, a total of 783, or about 52 fatalities per year due to the use of the trolley-locomotive system in the coal mines of the United States. Notwithstanding the numerous production advantages of the trolley system, it is evident that in the taking of 50 or more lives every year for the past 15 years by the trolley system, the mining people of the United States are paying far too high a price for the productive efficiency afforded by the trolley system. Moreover, there is every reason to believe that well-designed, constructed, and maintained Diesel locomotives, in addition to being much safer than trolley locomotives, are much more flexible and efficient than the electric-trolley system and are even more dependable as to continuity of operation and production.

CAN DIESEL LOCOMOTIVES BE USED WITH REASONABLE SAFETY IN AMERICAN MINES?

Diesel locomotives designed for use in underground gassy coal mines are no longer in an experimental stage in England and Continental Europe. The considerable number of this type of locomotive in service in underground coal and noncoal mines (gassy as well as nongassy) of Europe proves that they are successful in this application and studies by the Bureau of Mines, and a limited amount of actual experience in operation of Diesel locomotives in underground workings in the United States indicates that suitably designed and operated Diesel locomotives can and should be used in our mines.

The coal mines of Europe are worked differently than most American mines, but the hazards attending the use of Diesel locomotives underground are similar, owing to the occurrence of explosive gas and coal dust; however, all mines, both coal and noncoal, have the necessity of providing adequate air currents to dilute and carry away the exhaust gas of the Diesel equipment so it can be used safely, as well as without injury to health, this requirement merely accentuating the fact that all mines should be adequately ventilated.

The European practice of using Diesel mine locomotives for main-line haulage and for gathering purposes attests that this equipment is reasonably safe for use in gassy mines if ventilation is sufficient to meet the standards fixed for the maximum safe methane content of the mine air and the maximum allowable limit of toxic gases is not exceeded. The use of Diesel equipment in American underground mines is too limited to be of value in forming conclusions, except that it is certain that health hazards from toxic gases are readily controlled and also that the Diesel almost invariably removes many of the hazards of electrically operated equipment of certain types.

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Diesel equipment used underground must be kept in good repair at all times; this is a "must," if trouble is to be avoided. The safety devices on Diesel locomotives, such as the exhaust-gas conditioner and flame arresters, must be kept in good working order and must be used at all times when the Diesel equipment is operated underground; the ventilating air currents must be strong enough to keep the amount of toxic gases in the general mine air below the maximum limits regarded as safe for a working environment. If these conditions are kept in effect, the Diesel mine locomotive can be used with reasonable safety (and unquestionably with greater safety than trolley electric locomotives), and there is good reason to believe that ultimate haulage costs with Diesels will be lower and efficiency higher than with the trolley system.

SUMMARY AND CONCLUSION

The Diesel-powered mine locomotives used in underground European mines have been developed to a high degree of efficiency and safety for that service; approximately 1,300 Diesel mine locomotives are reported to be in use in European underground mines as of January 1, 1947.

The exhaust-gas conditioners, or scrubbers, absorb much of the aldehydes and oxides of nitrogen present in the exhaust gas of the Diesel engine and cool the exhaust gas to below the ignition temperature of any methane or dense dust clouds that may be present in the air in which Diesel equipment is used in underground coal mines.

The flame arresters placed on the air intake and exhaust of Diesel engines effectually prevent the ignition of explosive atmospheres in case of an engine backfire or from incandescent material carried by the exhaust gas. Flame arresters are so designed that they can be changed quickly and easily at the end of a shift and are of the type that can be cleaned with little trouble.

The Diesel mine locomotives used in the British Isles are required to have a Buxton certificate, which is the British equivalent of the Bureau of Mines permissibility requirements described in Schedule 22.

Some of the Diesel mine locomotives used in British, French, Belgian, and Holland coal mines are heavier and more powerful than any of the few now used in American mines. The heavier locomotives are used for main-line haulage, and the smaller types are used for gathering purposes.

Only four Diesel mine locomotives are used in underground mines in the United States, so far as now known, as of February 1, 1947; two are used in metal mines and two in nonmetallic mines. Adverse mining laws and regulations and the lack of knowledge as to how Diesel mine locomotives can be used underground with reasonable safety have prevented their adoption in American mines.

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The use of Diesel-powered equipment in underground mines is somewhat common in the Central States: Diesel trucks, shovels, caterpillar tractors and loaders, and Diesel-powered portable compressors are used successfully in underground limestone, clay, and lead-zinc mines of that area.

Ventilating air currents capable of diluting and carrying away the exhaust gases from Diesel equipment are the most important requirement when suitably designed Diesel equipment is used underground. The ventilating air currents should be induced mechanically so as to insure positive ventilation at all times. This is not done in many cases, particularly in the Central States in some of the large underground limestone mines; these mines have many openings, and the mine workings have large cross-sectional area, and mechanical ventilation, such as used in coal mines, is not practical. In some instances, air movement in the working environments is induced by ordinary disk-type fans, which create local air currents; the pistonlike effect of the large trucks moving in the relatively narrow and high haulageways can cause fairly strong air currents, especially if suitable measures are taken to control them.

The hazards attending the use of trolley-locomotive systems in underground mines, most of which can be avoided by the use of Diesel locomotives, include:

1. Contact of persons with bare trolley wire.
2. Contact of bare trolley wire with mine doors, timbering, roof, ribs, and curtains (fire hazard).
3. Arcs or sparks from poor or broken bonding, bad joints, or broken rails igniting coal or gas or timber ties.
4. Arcs or sparks from trolley wheel, harp, or shoe igniting combustible material such as brattice cloth, wood, gas, or dust.
5. Arcs or sparks from locomotive controller or motor igniting gas or dust.
6. Arcs or sparks from locomotive wheels on poorly bonded tracks.
7. Falls of roof bringing down trolley wire and touching cars or rail, igniting coal or gas.
8. Wrecked or derailed cars causing coal dust to be thrown into suspension and ignited by arcs from the fallen trolley wire.
9. Explosions of Cardox shells, explosives, etc., through short circuits on trolley haulage trips or cars.
10. Stray currents from poorly installed trolley system causing premature detonation of electrically fired explosives even in relatively remote parts of a mine.

The accident statistics compiled by the Bureau of Mines indicate the necessity of combating this cause of fatalities. In the 15-year period, 1930-44, inclusive, 428 persons were killed in the coal mines of the United States by contact with electricity in trolley wires and locomotives, 48 persons were killed by fires caused by the trolley-locomotive system, and 307 were killed by explosions caused by trolley wires and locomotives. An

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average of 52 persons a year have been killed in the coal mines of the United States during the past 15 years because of the use of the trolley-locomotive system.

Diesel mine locomotives and other Diesel equipment can be used in underground mines with reasonable safety if proper precautions are taken. In many instances, probably in most, Diesel mine locomotives are believed to be safer in underground coal and noncoal mines than electric trolley-type locomotives, because the hazards introduced by the trolley system are greater and more numerous than those caused by the Diesel engine. Few, if any, fatalities have occurred in the underground mines of Europe that can be attributed directly to the Diesel locomotive.

The advantages of using Diesel locomotives in underground mines, compared with trolley-locomotive systems, are many, not only from a safety standpoint but also in over-all operating economy. The Diesel mine locomotive obviates the necessity of extending trolley lines into new workings, maintaining existing trolley lines, bonding rails, and guarding trolley lines so that persons will not come in contact with the wire, and eliminates the trolley wire-contact hazard in established mines. Mine cars can be rerailed without fear of coming into contact with the trolley wire. The Diesel mine locomotive is much more flexible in underground haulage than trolley-locomotive systems, and in new mines if the haulage system is equipped with Diesels costs will be lower.

Many coal mines now use direct current electricity only for the trolley-locomotive system. The use of Diesel mine locomotives underground would eliminate the need for any direct-current electricity in the mine and would remove the hazards that attend its application underground.

The principal disadvantages of a Diesel locomotive are that mines using them must be ventilated correctly, as Diesel engines require virtually normal air to work efficiently and safely. Correct ventilation of a mine can hardly be classed as a disadvantage, but it is a "must" requirement.

When American manufacturers develop Diesel engines for safe and efficient underground use, this type of power unit probably will have applications in many coal, metal, and nonmetallic mines. Many State officials and officials of both coal and noncoal mines are keenly interested in the possible use of Diesel equipment in mines, but they are unwilling to make the installation until Diesel engines that are known to be safe for underground use are made available by manufacturers.

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APPENDIX A

PROCEDURE FOR TESTING DIESEL MINE LOCOMOTIVES FOR PERMISSIBILITY (FROM BUREAU OF MINES SCHEDULE 22)

TYPE OF ENGINE CONSIDERED FOR APPROVAL

Only locomotives equipped with engines of the compression-ignition type will be considered for approval. Such engines shall be designed to operate only on liquid fuel of flash point not less than 150°F. The starting mechanism shall consist of an explosion-proof electric motor or other device considered safe; engines using gasoline or other volatile fuel for starting will not be considered.

FUEL INJECTION

The fuel-injection system of the engine shall be so constructed that the mechanism controlling maximum fuel injection may be fixed definitely, permitting adjustment only by breaking a seal on a locked compartment, or by altering design. Provision shall be made in the fuel-injection system to permit suitable adjustment, in maximum fuel injection, for engine operation at different barometric pressures.

ENGINE INTAKE SYSTEM

Construction of Engine Intake System

The intake system of the engine (exclusive of the air cleaner) shall be of such construction that it will withstand internal pressure of 125 pounds per square inch, or such internal pressures as may be developed within it in explosion tests with gas-air mixtures, whichever is the greater. All joints in the intake system shall be formed by flanged metal-to-metal contacts designed in accordance with requirements for other types of explosion-proof equipment as outlined in the section of this schedule entitled "Joints and Machining Tolerances."

Intake Flame Arrester

The intake system of the engine shall be equipped with a flame arrester to prevent propagation of flame from the system to a surrounding inflammable atmosphere. The flame arrester shall be so designed and attached to the intake system that it may be removed readily for inspection, repair, replacement or cleaning. The flame arrester shall be so constructed that it may be cleaned readily. The flame arrester shall be of sufficiently rugged construction to withstand use in its intended application, and shall be so situated in the locomotive assembly that it is protected from damage.

The component parts of any flame arrester must be positively positioned. If a flame arrester of the spaced-plate type is used, the thickness of the plates must be at least 0.125 inch; the space between plates must be no

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greater than 0.02 inch; and the width of plates must be at least 1 inch. The unsupported length of the plates shall be such that deformation in the intended application shall not exceed 0.002 inch. Plates shall be of material not subject to corrosion in the intended application.

Air shut-off Valve in Engine Intake

A valve shall be provided in the engine intake system so that the supply of air to the engine may be shut off. This valve shall be operable from the driver's compartment and shall be so arranged that it may be actuated only when the fuel supply to the engine is shut off.

Air Cleaner on Engine Intake

An air cleaner of automotive type shall be included in the engine intake system. The air cleaner shall be situated in the intake system so that intake air shall pass through the cleaner before entering the intake flame arrester. The size and design of the air cleaner shall be such that resistance to air flow will not increase rapidly in dusty atmospheres.

Attachment of Gage to Engine Intake System

A vacuum gage shall be attached to the engine intake system at a point suitable for indicating total pressure drop through that system. The gage shall be graduated in inches of water and shall be situated in the driver's compartment.

ENGINE EXHAUST SYSTEM

Construction of Engine Exhaust System

The exhaust system of the engine shall be of such construction that it will withstand internal pressures of 125 pounds per square inch or such internal pressures as may be developed within it in explosion tests with gas-air mixtures, whichever pressure is the greater. All joints in the exhaust system shall be formed by flanged metal-to-metal contacts designed in accordance with requirements for other types of explosion-proof equipment as outlined in the section of this schedule entitled "Joints and Machining Tolerances."

Exhaust Flame Arrester

The exhaust system of the engine shall be provided with a flame arrester to prevent propagation or egress of flame or heated particles from the exhaust system to a surrounding inflammable atmosphere. The flame arrester shall be so designed that it is readily accessible for inspection, repair, replacement, or cleaning. The flame arrester shall be of sufficiently rugged construction to withstand use in its intended application and shall be so situated in the locomotive assembly that it is protected from damage.

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The component parts of any flame arrester must be positively positioned. If a flame arrester of the spaced-plate type is used the thickness of the plates must be at least 0.125 inch; the space between plates must be no greater than 0.02 inch; and the width of plates must be at least 1 inch. The unsupported length of the plates shall be such that deformation in the intended application shall not exceed 0.002 inch. Plates shall be of material not subject to corrosion in the intended application.

Exhaust Cooling System

A cooling system shall be provided for the exhaust gas of the engine. The heat-dissipation capacity of this cooling system shall be such that the temperature of the undiluted exhaust gas shall not exceed 160°F. at the point of discharge from the cooling system under any condition of operation. A device shall be provided which shall stop the engine automatically and immediately if the temperature of the exhaust gas reaches 180°F. at the point of discharge from the cooling system.

Cooling preferably shall be obtained by a water spray entering the exhaust system at a point close to the outlet of the exhaust manifold or by passing the exhaust gas through water in suitable containers, or by a combination of the two. If a water spray is used, the water shall be delivered to the spray nozzle by a pump, and the water shall pass through a filtering device to protect the spray nozzle from clogging by extraneous material. Provision shall be made for draining and cleaning all exhaust cooling boxes included in the locomotive assembly.

If cooling equivalent to that obtained by the use of water can be provided by other means, such means may be considered acceptable.

Control of Surface Temperature of Exhaust System

Provision shall be made for limiting the temperature attained by the external surfaces of the exhaust system. The temperature of such surfaces shall not exceed 400°F. under any condition of engine operation. If water-jacketed parts are used the jackets shall be integral with the parts in question. Insulating coverings that would absorb oil will not be considered acceptable.

If a water spray is employed to reduce the temperature of the exhaust gas, as mentioned under "Exhaust Cooling System," the spray shall be situated as closely as possible to the outlet of the exhaust manifold to aid in reducing surface temperature of this portion of the exhaust system.

Exterior surfaces of the exhaust system shall be designed to minimize accumulation and lodgment of combustible dusts and to permit ready access to these surfaces for cleaning.

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Dilution of Exhaust Gas

Provision shall be made to dilute the exhaust gas with air before it is discharged from the locomotive into the surrounding atmosphere. The quantity of diluting air shall be such that the discharged mixture of exhaust gas and the air shall not contain more than 100 parts per million, by volume, of carbon monoxide; 25 parts per million, by volume, of oxides of nitrogen (as equivalent nitrogen peroxide); or 10 parts per million, by volume, of aldehydes (as equivalent formaldehyde) under any condition of operation.

The final (diluted) exhaust of the locomotive shall be discharged in such manner that it is not directed toward the locomotive operator's compartment and shall be deflected downward so that persons alongside the locomotive do not encounter the exhaust at breathing level.

Temperature-Indicator in Exhaust System

A temperature-indicating device shall be provided in the exhaust system to indicate the temperature of the undiluted exhaust gas after its final contact with cooling water. The indicating portion of this device shall be situated in the operator's compartment of the locomotive.

Provision for Attachment of Gage or Gas-sampling Equipment to Exhaust System

A connection shall be provided in the engine exhaust system for temporary attachment of a gage at a point suitable for measuring the total back pressure in that system. This connection shall be suitable also for temporary attachment of gas-sampling equipment to the exhaust system. This opening into the exhaust system shall be provided with a locking closure.

COMPOSITION OF EXHAUST GAS

Under normal operating conditions, and within the rated power output range, the undiluted exhaust gas of the engine shall not contain more than 0.25 percent, by volume, of carbon monoxide.

LOCOMOTIVE FUEL-SUPPLY SYSTEM

Fuel Tank

The fuel tank shall be fuel-tight and shall be of metal at least 1/16 inch thick welded at all seams. The fuel tank shall be provided with a drain plug (not a valve or petcock) that shall be locked in position when inserted. The fuel tank shall be provided with a vent opening of such design that atmospheric pressure is maintained inside the tank and that discharge of liquid fuel from the vent opening is prevented. Construction of the fuel tank shall be such that fuel may be added to the tank only through a self-closing valve situated at least 1 foot from the exhaust manifold of

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the engine and preferably below it. The self-closing valve shall constitute a fuel-tight closure when fuel is not being added. Any part of the self-closing valve that would be detached during the addition of fuel shall be secured to the locomotive to prevent loss.

The fuel tank shall be a built-in unit comprising part of the locomotive assembly, and no provision shall be made for attachment of separate or auxiliary fuel tanks to the locomotive.

Fuel Lines

All fuel lines to the engine and its accessory parts shall be installed so that they are not subject to damage in ordinary use and shall be designed to resist breakage from vibration.

Valve in Fuel Line

A shut-off mechanism, operable from the driver's compartment, shall be provided in the fuel system so that the engine may be stopped immediately in an emergency.

SIGNAL OR WARNING DEVICES

All locomotives shall be equipped with a bell, horn, or other suitable warning device. This device shall not be electrically operated.

ELECTRICAL EQUIPMENT

Classification of Electrical Parts

The electrical parts of a locomotive that may cause ignition of mine gas and coal dust are classified as follows:

Class 1. - Class 1 shall include motors, starting switches, fuses and all their parts that may produce sparks or flashes as the result of normal operation. Headlights, motors, rheostats, electromagnets, and similar parts which may become dangerous because of failure of electrical circuits in them are also included in this class. Parts in this classification shall be enclosed in explosion-proof casings.

Class 2. - Class 2 shall include all parts, such as batteries and external connections and wiring between enclosures, that do not produce sparks or flashes as the result of normal operation but may do so as the result of accident. Parts in this classification shall have adequate shields or guards of a strength and character proportionate to the risk of injury, or else they shall be enclosed in explosion-proof casings.

Class 3. - Class 3 shall include all parts such as plugs and receptacles that may produce sparks or flashes in normal operation, but are not of necessity operated while the locomotive is in a gassy place. Parts in

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this classification shall be enclosed in explosion-proof or adequately locked casings. If locked casings are used, they shall have adequate mechanical strength.

Type of Electrical System

The electrical system on the locomotives shall be completely insulated from the chassis, the engine, and all other metal parts.

Automatic Protection of Electrical Circuits and Equipment

On locomotives using storage batteries for starting of engines, each electrical conductor from the battery to the starting motor shall be protected against short circuit by fuses or other suitable automatic circuit-interrupting devices placed at the battery unless conductors of adequate size are provided.

Fuses or other automatic circuit-interrupting devices shall be inserted at the point where branch circuits are connected to the main circuit between the charging generator and battery. Headlight circuits and circuits for instruments and instrument panel lights are construed as being branch circuits.

Fuses shall be enclosed in explosion-proof casings with locked or sealed covers.

Conductors, Conduits, and Wiring

Every conductor shall have adequate insulation from "ground" and from conductors of opposite polarity. Insulation shall be selected with special reference to its ability to resist deterioration from engine heat and oil.

It is recommended that all conductors have a carrying capacity of not less than 110 percent of the total current rating of the motor or other load connected to them. The basis for determining such carrying capacity shall be that given by the National Electrical Code for "allowable carrying capacities of wires."

All wiring, particularly that outside of locked or explosion-proof enclosures, shall have adequate mechanical and electrical protection to minimize gas-ignition hazards as well as fire hazards. If for any reason rigid conduit is unsuitable or undesirable a good grade of rubber air hose or equivalent may be construed as meeting the requirement for mechanical protection if used where it will not be damaged by engine heat and oil. Flexible metal conduit is not acceptable. All conduit ends must be adequately clamped or otherwise secured to prevent their being pulled out. Inserts should be used to prevent collapse of hose conduit ends that are secured by external clamps.

Sharp edges and corners shall be removed at all points where there is possibility of damaging the insulation of wires, cables, or conduits by cutting or abrasion.

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Wiring and conduits shall be well-cleated or otherwise held to prevent vibration and displacement.

The ends and terminal lugs of wires and cables shall be held or clamped in a manner that will minimize the possibility of the ends and lugs coming loose from their connections and swinging against sides of enclosing casings or against parts of opposite polarity.

Electrical Clearances and Insulation

The clearance between live parts and casings of electrical equipment shall be such as to minimize the possibility of arcs striking to the casings, or if space is limited the casings shall be lined with adequate insulation.

H/S 407/59.

APPENDIX B

BUXTON CERTIFICATE REQUIREMENTS, GREAT BRITAIN

Diesel Engine Locomotives for Use in Coal Mines

Requirements as to design, construction and official test

1. Design:

(a) The general design of the engine shall comply with the normal requirements for flameproof enclosure, with joints made between close-fitting metal-to-metal surfaces, except that the use of packing material, e.g., metal gaskets comprising metal-enclosed asbestos sheets, will not be excluded where such packing is essential in order to obtain a pressure-tight joint.

(b) A protective device (flame arrester) shall be fitted to both the air inlet and to the exhaust conditioner of the engine, and the design of the protective device shall comply with the general requirements for flameproof enclosure, with such additional requirements in detail as may be deemed necessary following examination and test of the device as prescribed hereinafter. The protective device shall be designed as a complete separate unit so that it may be removed for examination and replacement, as required, without disturbing the associated parts of the engine.

(c) The component parts of inlet protective device, the exhaust conditioner box, and the exhaust protective device shall be constructed in best-quality stainless steel or such other incorrodible material as may be decided upon in consultation with the manufacturer before or during the tests on these components.

(d) If the presence of water forms an essential feature of the exhaust-conditioning arrangement, an interlocking device shall be provided to cut off the fuel supply to the engine automatically in the

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event of the water in the conditioner box or the associated water supply tank falling a pre-determined amount below normal level.

(e) The exhaust pipe shall be screened in such a manner as to prevent accidental contact with the heated surface.

(f) The brake blocks and/or the brake-block linings for the wheels of the locomotives shall be of a type designed to minimize sparking by frictional contact, and the design of the braking device as a whole shall, as far as is practicable, be such as to minimize locking of the wheels and consequent frictional contact between the wheels and the rails.

(g) The efficiency of the engine shall be such that, in association with the exhaust-conditioning arrangements and with due allowance for any back pressure introduced by the exhaust protective device, the emission of smoke or pungent fumes from the exhaust or the crank case will be minimized as far as is practicable.

(h) The radiator-cooling fan shall be constructed and mounted in such a manner as will minimize the possibility of contact between the fan blades and adjacent parts.

2. Examination and Test:

(a) The general design of the engine, and the constructional details of the exhaust conditioner box and the protective device, will be examined in conjunction with relevant drawings and the specifications of the makers, as to compliance with the requirements prescribed under Item 1.

(b) Tests will be made to prove the effectiveness of the protective device (flame arrester) when fitted to the particular exhaust-conditioner box with which it is to be associated. In general, the tests will be the standard tests for flameproof enclosure. With this apparatus the test will be made with pentane vapour, to represent petroleum vapour, applied under controllable conditions within the exhaust-conditioner box. Further tests under similar conditions shall be made to prove the effectiveness of the protective device when fitted to the air-inlet component of the engine, should the design and/or the method of applying the device to the air inlet be such as to warrant the additional tests.

(c) Tests will be made to obtain evidence, under running conditions, that the engine does not in any part attain such an internal temperature as to be likely to ignite coal dust or other inflammable material.

(d) The examination required under Item 2(a) will be carried out on the premises of the makers or their agents or at the Ministry of

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Fuel and Power Testing Station at Buxton. The evidence required under Item 2(c) will be obtained by trial runs, against a controllable brake load or equivalent means, on the premises of the makers or their agents or at the Ministry of Fuel and Power Testing Station at Buxton, as may be most convenient.

M O D E L C O D E

COAL MINES ACT, 1911

SPECIAL REGULATIONS FOR THE USE OF DIESEL OR STORAGE-BATTERY LOCOMOTIVES (INCLUDING SHUTTLE CARS) BELOW GROUND

NOTE: - When the Minister of Fuel and Power consents to the introduction of Diesel or Storage Battery Locomotives (including shuttle cars) into any mine, his consent is subject to the establishment of appropriate Special Regulations to regulate their use.

This model code is intended as a guide in drawing up suitable Special Regulations in any particular case. It is in three parts: Regulations 1-24, applicable to both systems of traction; Regulations 25-33, applicable only to Diesel Locomotives; and Regulations 34-41, applicable only to Storage Battery Locomotives. Where necessary, alternatives are provided for safety-lamp mines and naked light mines.

ROADS AND TRACK

1. Locomotives shall only be used on such roads or in such districts and at such distances from the working face as may be specified in writing by the Inspector of the Division on the application of the manager. Any such specification may be varied or withdrawn at any time.

2. No locomotive shall be used on any road on which there is a gradient exceeding 1 in 10 for a shuttle car or 1 in 12 for any other locomotive.

3. In the case of rail tracks -

(a) The track shall have adequate strength and rigidity, and shall be properly laid and maintained; and
(b) there shall be a clearance of at least one foot above and on one side of the locomotive and at least two feet on the other side.

4. Every road on which locomotives are used shall be placed in charge of a competent person appointed in writing by the manager, and once at least in every 24 hours the competent person shall inspect the whole of every such road with respect to its clearance and freedom from obstructions and the state of the track and to the presence of gas, ventilation, state of roof and sides, coal dust, and general safety, and shall make a full and accurate report in writing to the manager.

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VENTILATION (SAFETY LAMP MINES ONLY)

5. The following Regulations 6, 7, and 8 shall apply to seams in which safety lamps are used.

6. An application to the Inspector of the Division in accordance with Regulation 1 shall be accompanied by the following particulars:

(a) In the case of locomotives running on rails -

(i) The quantity of air passing and the percentage of inflammable gas present in the general body of the air determined on each shift over a period of not less than six consecutive working days at each end of the road or part of a road on which locomotives are proposed to be used and at every intermediate point where air from a split enters the road; provided that with respect to any main intake airway commencing at a shaft or outlet to the surface the percentage of inflammable gas shall not be required to be determined except within 300 yards of the face;

(ii) Any other air measurement taken in pursuance of the Act or the regulations of the mine during the four weeks preceding the application on the road or part of a road on which locomotives are proposed to be used;

(iii) Extracts from the reports made in pursuance of Sections 64 and 65 of the Act with respect to any occasions on which deputies have reported the presence of inflammable gas during the previous three months in the ventilating district in which the locomotives are proposed to be used; and

(iv) Any other particulars relating to the state of the ventilation on the road or part of a road on which locomotives are proposed to be used which are available or which the Inspector of the Division may require.

(b) In the case of shuttle cars -

(i) Such particulars, including air measurements and determinations of inflammable gas, as will provide a full and accurate description of the state of the ventilation in the ventilating district in which the shuttle cars are proposed to be used;

(ii) Extracts from the reports made in pursuance of Sections 64 and 65 of the Act with respect to any occasions on which deputies have reported the presence of inflammable gas during the previous three months in the ventilating district in which the shuttle cars are proposed to be used; and

(iii) Such other particulars as the Inspector of the Division may require.

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7. In every road or part of a road on which locomotives are used:

(1) The quantity of air passing and the percentage of inflammable gas present in the general body of the air shall (except as hereinafter provided) be determined once at least in every week, and whenever any alteration is made in the quantity of air circulating -

(a) in the case of locomotives running on rails, at each end of the road or part of a road on which they are used, or

(b) in the case of shuttle cars, at each end of the district in which they are used, and

(c) in all cases, at such intermediate points as may be fixed by the manager with the approval of the Inspector. Provided that with respect to any main intake airway commencing at a shaft or outlet to the surface the percentage of inflammable gas shall not be required to be determined except within 300 yards of the face.

(2) If the percentage of inflammable gas in any sample exceeds 0.75 determinations shall be made at intervals not exceeding 24 hours for so long as the percentage continues to exceed 0.75 and for at least six working days thereafter;

(3) If and so long as the percentage of inflammable gas does not exceed 0.25 in any sample, it shall suffice for determinations to be made once at least in every month;

(4) The samples shall be taken by a competent person appointed by the manager, in writing, for the purpose, and at times when experience shows that the percentage of inflammable gas is likely to be greatest; and a written record of the results shall be made within seven days.

8. If in any road or part of a road on which locomotives are used the percentage of inflammable gas present in the general body of the air is found to exceed 1.25, or if any indication of inflammable gas is seen on the lowered flame of a safety lamp in the general body of the air -

(a) The official in charge of the district shall immediately be informed, and the use of locomotives shall be discontinued forthwith on that road or that part of the road; the manager shall also be informed as soon as possible;

(b) The use of locomotives shall not be recommended except on the instruction of the manager after steps have been taken to improve the ventilation and it has been ascertained by analysis of samples of the air that the percentage of inflammable gas present in the general body of the air does not exceed one percent; and

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(c) The owner, agent or manager shall without delay report to the Inspector of the Division any circumstances in which the use of the locomotives is discontinued because of the presence of inflammable gas.

DESIGN AND OPERATION

9. (Safety lamp mines) With respect to -

(a) the protection of parts from which open flame or hot or noxious gases are liable to issue in ordinary working; and

(b) the safety of electrical enclosures and of parts and accessories at which open sparking is liable to occur in ordinary working; and

(c) the enclosure or protection of cables and other parts to avoid the risk of fire -

every locomotive shall be of a type which has been approved by the Minister, and all parts of the locomotive and its accessories shall be properly maintained in their designed condition.

9. (Naked light mines)

(a) The exhaust from the engine of every diesel locomotive shall be fitted with a trap to prevent the emission of sparks or flame, and so far as possible the emission of smoke or pungent fumes.

(b) Every storage-battery locomotive and all accessories used in conjunction therewith shall be constructed as far as possible of non-inflammable material, and any inflammable material which has to be used shall, as far as possible be shrouded by a substantial metallic covering.

10. Every locomotive shall be provided with -

(a) a speed indicator so placed as to be readily seen by the driver;

(b) an efficient headlight and means for giving an audible warning signal; and

(c) a suitable type of portable fire extinguisher so placed as to be within easy reach of the driver.

11. Once at least in every 24 hours -

(1) Every locomotive shall be examined by a competent person appointed, in writing, by the manager;

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(2) The flameproof trap fitted to the exhaust opening of the engine of a Diesel locomotive shall be detached and replaced by a trap in clean condition.

12. Once at least in every seven days -

(1) Every locomotive shall be examined by a competent engineer appointed, in writing by the manager, who shall see that it is in all respects in proper working order;

(2) (Safety-lamp mines). In the case of a Diesel locomotive he shall see that the flameproof trap fitted to the inlet opening of the engine and the inlet and exhaust valves of the engine are cleaned as often as is found necessary.

12. (2) (Naked-light mines). In the case of a Diesel locomotive he shall see that the inlet and exhaust valves of the engine are cleaned as often as is found necessary.

13. (1) The braking system of every locomotive shall be maintained in good working order, and once at least in every seven days and after any repairs or adjustments have been made it shall be thoroughly examined and tested by a competent person appointed in writing by the manager.

(2) The test shall include:

(a) an application of the brakes when the locomotive is moving and

(b) except in the case of shuttle cars, a continuous application of the brakes for a period of at least ten minutes with the engine stopped.

14. Reports of the examinations required to be made under Regulations 11, 12, and 13 shall be recorded in a book by the persons making the examinations.

15. No locomotive shall be used if it has any defect liable to affect its safe running.

16. (1) The driver of a locomotive shall be appointed in writing by the manager, and when the locomotive is used for conveying persons he shall not be less than 21 years of age.

(2) Without prejudice to the generality of the provisions of Article 1 of the Coal Mining (Training and Medical Examination) Order, 1944, and any amendment or variation thereof, no person shall be appointed to be the driver of a locomotive unless he has been adequately trained by a skille driver and is certified by him in writing to be competent to drive without supervision.

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17. The manager shall -

(a) fix by notice the maximum load to be hauled by each locomotive and the maximum speed of trains on each road; and

(b) cause cautionary notices to be posted in the roadway wherever special precautions are necessary to ensure the safe running of trains; and

(c) give to each driver directions in writing with respect to loads, speed and all such other matters as are necessary to ensure the safe running of trains.

18. No workman other than the driver and the shunter shall ride on any locomotive except with the permission of the manager for purposes of training or testing.

19. Except when engaged in shunting operations, a locomotive shall always be in front of the train.

MAN-RIDING TRAINS

20. (a) The locomotive shall be used in connection with the riding of a shift of persons only if,

either (i) the shift is ridden in a train of carriages suitably designed and used only for that purpose,
or (ii) the shift is ridden in a set of mine cars each of at least 30 cwts. coal capacity and in good order and repair.

(b) On roadways used only for riding persons, the trains shall be provided with a braking system such that it can be operated from the locomotive and from the last carriage, even if it becomes detached, and means shall be provided in the locomotive and on each carriage for keeping the brake applied.

(c) On roadways used for the haulage of mineral and also for riding persons in mine cars, the braking system of the locomotive shall be such that the train is at all times under adequate control, and no workman shall ride on any train in which mineral is hauled. Where the train consists of more than one car the cars shall be fitted with a means of attachment in addition to the ordinary coupling.

21. The manager shall by notice fix the maximum number of persons who shall ride in each carriage and the maximum number of persons who shall ride in each train.

22. The person appointed in pursuance of No. 23 of the General Regulations of 10th July, 1913, to have charge of a train (hereinafter called

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the guard) shall be appointed in writing by the manager and shall not be the driver of the train.

23. (a) On taking over a train used exclusively for riding persons and after the locomotive or any carriage has been coupled or uncoupled, the driver and the guard shall test the braking system of the locomotive and the emergency braking system, and each shall satisfy himself that both systems function effectively.

(b) Before a train of mine cars is used for riding persons, the driver of the locomotive shall test the braking system and shall satisfy himself that it functions effectively. The guard shall see that all the mine cars are properly coupled.

24. Each carriage and coupling shall be maintained in proper working order and shall be examined by a competent person, appointed by the manager, once at least in every 24 hours.

REGULATIONS APPLICABLE ONLY TO DIESEL LOCOMOTIVES

General

25. No locomotive shall be run into any unventilated road.

26. The engine shall not be kept running while a locomotive is stationary, except for short periods when necessary.

27. A sample of exhaust gas from every locomotive shall be analysed once at least in every three months, and the locomotive shall be deemed to be defective if the exhaust gas at any time contains more than five parts per thousand of carbon monoxide.

Fuel and Filling Arrangements

28. The oil used as fuel -

(a) shall have a flashpoint of not less than 150 degrees Fahrenheit as determined in the manner indicated in the current British Standard Specification (No. 209);

(b) shall only be taken below ground in sufficient quantity for one day's working; and

(c) shall be taken below ground in strong receptacles which do not leak.

29. The oil tanks shall be filled only at a filling station appointed by the manager and approved by the Inspector of the Division.

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30. (1) Each filling station shall have a floor of smooth concrete provided with a sill, and if the filling station is a room it shall also be -

(a) ventilated by a through current of air;

(b) provided with two separate means of egress; and

(c) constructed of non-inflammable material.

(2) Adequate means for extinguishing fires shall be kept constantly available at each filling station.

31. (1) Adequate means shall be provided to avoid as far as possible spillage of oil during the filling of oil tanks.

(2) Any oil spilt shall be at once taken up with sand, deposited in a fireproof receptacle, and removed from the mine at suitable intervals.

32. In mines where safety lamps are not used throughout, no lamp other than a locked safety lamp or an electric lamp enclosed in a suitable and substantial fitting shall be used in or within 10 yards of any filling station, and no person shall smoke in or within 10 yards of any filling station.

33. A copy of Regulations 28 to 33, inclusive, shall be kept posted at each filling station.

REGULATIONS APPLICABLE ONLY TO STORAGE-BATTERY LOCOMOTIVES

General

34. The batteries shall be contained in suitable and substantial enclosures designed to resist rough usage and fitted with suitable ventilators to disperse the gases evolved.

35. The working voltage at the battery terminals shall not exceed ***.

Charging Stations

36. If the batteries are charged or changed below ground, this shall only be done at a charging station appointed by the manager and approved by the Inspector of the Division.

37. Each charging station shall be adequately ventilated to render harmless the gases evolved, and the charging apparatus shall be installed on the intake side of the battery racks, so that the ventilation passes from the battery racks direct into the return airway.

38. No inflammable material shall be used in the construction of any charging station.

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39. Adequate means for extinguishing fire shall be kept constantly available at each charging station.

40. In mines where safety lamps are not used throughout, no lamp or light other than a locked safety lamp or an electric lamp enclosed in a suitable and substantial fitting shall be used in or within 10 yards of any charging station, and no person shall smoke in or within 10 yards of any charging station.

41. A copy of Regulations 36 to 41, inclusive, shall be kept posted up at each charging station.

SCHEDULE

COAL MINES ACT, 1911

Special Regulations for the use of Internal-Combustion Engines Underground

1. The engine room shall have a traveling road, at least four feet wide and four feet high, communicating direct with a main return air-way or with a return air-way which communicates direct with a main return air-way, through which the air current which ventilates the engine-room shall pass to the main return air-way.

2. The engine-room shall be continuously and thoroughly ventilated and so as to dilute and render harmless all fumes produced by the engine.

3. The petroleum shall be conveyed into the mine in strong, sealed tanks so made and maintained as to be entirely free from leakage, and fitted with a pump for filling and emptying or a closed pipe which allows the engine tank to be filled by gravity, and the tanks shall only be filled and emptied by means of such pump or closed pipe.

4. The petroleum shall only be taken into the mine in quantity sufficient for one day's working of the engine, except at a week-end, when a sufficient supply for two days may be taken into the mine.

5. When the tank of the engine is being filled with petroleum from the sealed tanks the petroleum shall not be allowed to come into contact with the atmosphere.

6. If the tank of the engine is detachable it shall be taken out of the mine whenever it is necessary to clean it.

7. The sealed tanks when taken into the mine shall either be kept, except when required for use, in a securely closed chamber which shall be situated on the intake side of the engine-room at a distance of not less than 20 yards, or shall be kept in the mine only so long as is necessary to convey them to and from the engine and to fill the engine tank.

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8. Any spilt petroleum shall be at once covered or taken up with sand.

9. Unless the place where the engine is situated and all places within a radius of ten yards thereof are naturally wet throughout, the roof, floor and sides, for a distance of at least ten yards in all directions, shall be kept free from dust, and the roof and sides shall be kept thoroughly whitewashed for the same distance.

10. No wood or other inflammable material shall be used or allowed to remain in the vicinity of the engine-room.

11. No lamp or light other than locked safety lamps shall be used within the engine-room except when lighting up.

12. No petroleum shall be used for the purposes of the engine which has a flash point below 100 degrees Fahrenheit when tested in the manner set forth in the First Schedule to the Petroleum Act, 1879.

13. The waste oil from the engine and the refuse cotton-waste shall not be allowed to accumulate, but shall be sent out of the mine daily.

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